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PREFACE

This bulletin contains most of the papers that will be discussed at the sixth meeting of the WPRS working group "Integrated control in Glasshouses" which will be held in Budapest, Hungary from 25-30 April 1987. It is the first time a combined meeting is organised with members of the EPRS Glasshouse IPM working group, although several members of the EPRS group attended previous meetings of the WPRS group. I am very thankful to the boards of the EPRS and WPRS sections for allowing us to have such a combined meeting. Further this meeting would not have been possible without the activity of our colleagues at the Plant Protection and Agrochemistry Centre at Budapest and those at the Plant Protection and Agrochemistry Station at Hődmezövásárhely (both Ministry of Agriculture and Food, Hungary). Finally, I like to thank Barbro Nedstam and Lise Sténgard Hansen for their help in preparing these proceedings and part of the meeting.

Since the last meeting in Darmstadt in 1982 developments in greenhouse biological control have been fast. Around 1980 the area on which biological control was applied seemed to level off, but after 1982 considerable increases occurred in application of *Encarsia formosa, Phytoseiulus persimilis* and three parasites of leafminers. *Bacillus thuringiensis* is becoming popular as control agent for Lepidoptera and the control of thrips with *Amblyseius* spp. has definitely broken through. *Aphidoletes,* although known for a long time as a good predator of aphids, is still used on a small scale only. Also the use of entomopathogenic fungi (*Aschersonia* and *Verticillium*) for control of aphids and whitefly do not play an important role as yet. One of the most recent developments in greenhouse biological control is a nuclear polyhedrosis virus as biological control agent of *Spodoptera exigua.* Further biological control of diseases of greenhouse crops seems to mature. I am convinced that the Budapest meeting will be an excellent opportunity to review progress and to develop future plans.

J.C. van Lenteren,
convenor.

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EXPERIENCES WITH THE INTRODUCTION OF BIOLOGICAL CONTROL METHODS INTO GLASSHOUSES IN SOUTHWEST-GERMANY

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Summary

In Baden-Württemberg more than 11% of the total glasshouse area with vegetables are protected with beneficials against noxious arthropods. Especially in the district of Stuttgart the BC/IPM was successful because of the Stuttgart model. Within the framework of the model 16 of 19 advisors of the plant protection service started to introduce the BC/IPM in at least one glasshouse in 1980. The plant protection institute accompanied the model scientifically, it also searched for alternative methods to introduce BC into glasshouses. The realized BC/IPM with Phytoseiulus persimilis and Encarsia formosa and the integration of these beneficials and pesticides are demonstrated. Experiences with tests of other beneficials and difficulties with the integration of fungicides against the false powdery mildew are discussed.

1 Realized application of biological control (BC)/integrated pest management (IPM)

In Baden-Württemberg more than 11% of the total glasshouse area with vegetables are protected with beneficial arthropods. This biological control in glasshouses is intensively supported by the plant protection service (Tab. 1, see last page of paper). As can be seen, Tetranychus urticae and Trialeurodes vaporariorum are the most important pest species, Phytoseiulus persimilis and Encarsia formosa their natural antagonists.

2 Historical development of BC/IPM in Baden-Württemberg

Especially in the administrative district of Stuttgart the BC/IPM in glasshouses has been very successful because of the "Stuttgart model". 16 of 19 advisors of the plant protection service were willing in 1980 to take part in an experiment for the introduction of BC/IPM in the district. Each advisor had to supervise a pilot plant with cucumbers and/or tomatoes. He was responsible for the supply with beneficial arthropods, the monitoring of the pest populations and of beneficials and for the distribution of the beneficials. The aim of the experiment was at first to show the owner of the glasshouse that BC/IPM is possible in practice. The pilot glasshouse should also serve as an example for other growers in the surroundings. After some initial problems in the first years more and more farms have been convinced by the experience with the pilot glasshouse to take part in BC/IPM, so that today altogether 152 plants have to be supervised in the

Stuttgart district. Nowadays the advisor has in many cases to provide the beneficials only and is asked for help in the case of doubt. All the other steps are done by the management of the plants.

Initially the use of P. persimilis brought problems. The increase of the predatory mite was often too slow in cucumbers with high infection rates of T. urticae. Also the important integration of chemical and biological control posed problems, moreover it was not within sight, whether the owners of the glasshouses would be able to do all the important steps for BC/IPM themselves. To solve these problems, the Landesanstalt für Pflanzenschutz (Plant Protection Institute) Stuttgart looked intensively for possibilities to improve the BC/IPM. For this aim, some plant protection procedures and other beneficial organisms were tested in glasshouses and it was tried to put them into practice.

The emphasis was put upon the periodical education of about 12 to 15 interested growers, who were intensively acquainted with the BC/IPM in glasshouse in theory and practice.

Not only the supervision of the gardeners by the local plant protection service but also the efforts of the Landesanstalt für Pflanzenschutz brought different degrees of acceptance. Both ways enabled many growers to do the BC/IPM themselves as mentioned above. Failures depended mainly on difficulties of the growers to understand the procedure or on lack of time for essential steps of BC at the right moment. Because of these reasons, many growers would prefer a commercial distribution of beneficials by advisors or by producers of the beneficial arthropods, a method which is successfully used in the Netherlands. However, such a service is impeded in the South of Germany by the long distances between interested growers.

A supervision of the growers, even of those, who do the BC/IPM themselves, by private or public advisors will be necessary in future. A scientific supervision and development, which takes into account the special climatic conditions of Southwest Germany, would be helpful for maintaining the BC. But especially important for the successful extension of BC is the continuous supply with accurate and sufficient beneficial material.

2 Biological control/IPM in development

Within the framework of the above mentioned activities of the Landesanstalt für Pflanzenschutz several species of beneficial organisms have been tried against different pest species in glasshouses (tab. 2). The results were different for the tested species. Some of them can be expected to play an important role in future practice.

Tab. 2. Experience with some beneficial organisms in commercial glasshouses

pest/disease	crop	beneficial	success
different Thrips species	cucumber sweet pepper	Amblyseius cucumeris	sufficient to good
Trialeurodes vaporariorum	cucumber	Verticilium lecanii	bad, even at high air humidity
Brevicoryne brassicae	cabbage	Verticilium lecanii	good
Otiorrhynchus sulculatus	ornamental shrubs strawberries	Heterorhabditis spec.	good
Liriomyza trifolii	chrysanthemum	Diglyphus issea	good
aphids	cucumber sweet pepper	Chrysopa carnea	bad good

The false powdery mildew (Pseudoperonospora cubensis (BERK. et CURT.) ROSTOVZ.) on cucumbers has become a severe problem for BC in Baden-Württemberg over the last three years. Since 1984, it damages cucumber plants every year whereas before damage occured only about once every decade. The side effects of some fungicides effective against this fungus were tested on the beneficial P. persimilis (tab. 3). Up to now only the active ingredient with the highest rate of mortality for P. persimilis has received permission for cucumbers. If no chemicals more acceptable for the beneficials can be used in future, the BC in glasshouses will be endangered in Southwest Germany.

Tab. 3. Influence of some fungicides on the predatory mite P. persimilis. The fungicides were used on plants in a commercial glasshouse. After six days the surviving mites left the plants because of food shortage and the experiment ended.

trade name	compound	conc. (%)	% mortality of P. persimilis in 6 days
Previeur	Propamocarb	0.25	1
Aliette	Fosetyl	0.5	4
Ridomil-Combi	Folpet and Metalaxyl	0.23	6
Dithane Ultra	Mancozeb	0.2	25

3 Suggestions for discussion, questions, ideas for cooperation/research

- I suggest a better exchange of beneficial species between the Eastern and Western hemisphere, for example: Aschersonia- or Beauveria bassiana-formulations.

- Does a strain of E. formosa exist in which the adult individuals are resistent against different pesticides?

- What is the best way of distributing the predatory mite Phytoseiulus persimilis in a glasshouse: a) to deposit the predators on and around heavily infested cucumber plants, b) to distribute it regularly on every plant, c) to distribute it on every second, third or so on plant? Does one of the distribution methods save the very laborious redistribution of P. persimilis from plants with high densities to plants without predatory mites but enough spider mites?

- A Dutch company sells Amblyseius species against Thrips to be used on sweet pepper. Has anyone experience with this predator on other plant species, even ornamental plants?

- Does anyone know whether there exists a flying predator used successfully against Tetranychus urticae in glasshouses?

- Does a practical alternative exist to the chemical control of the powdery mildews (Peronosporaceae)?

Tab. 1. Realized biological control on vegetables in glasshouses in Baden-Württemberg

pest/disease	crop protection program as applied in practice	crop	area (ha)	cost aspects as compared to chemical control	chemical control	integrated chemicals
Trialeurodes vaporariorum	Encarsia formosa single to 2-fold or 3-to 4-fold distribution of a third part to total amount	tomato cucumber aubergine	12.8 7.6 0.4	cheaper cheaper to more expensive	difficult because of resistent tribes	Dichlofluamid Iprodion Vinchlozolin Pirimicarb Pyrazophos Sulfotepp Mevinphos
Tetranychus urticae	Phytoseiulus persimilis, 1 to 2 times	cucumber aubergine bean	8.7 0.4 0.4	cheaper to more expensive	possible, but resistence problems in some tribes	
different Aphidae	Aphidoletes aphidimyza, 1 to 2 times	sweet pepper	0.5			

ENCARSIA TRICOLOR VS. ENCARSIA FORMOSA: THEIR USE IN BIOLOGICAL CONTROL OF TRIALEURODES VAPORARIORUM IN SPANISH CONDITIONS.

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Summary

A review of the present knowledge on the biological features of *Encarsia tricolor* is done and the possibilities of its use in IPM programmes in Spain are discussed with a view to the possibility of favouring the control of *Trialeurodes vaporariorum* in field crops during the summer.

1.1. Introduction

Protected and field vegetable crops coexist or alternate throughout the year in widespread areas along the Mediterranean coast. Polyphagous phytophagous like *Trialeurodes vaporariorum* Westwood, have continuous access throughout the year to host plants under favourable climatic conditions which allow their populations to grow beyond economic thresholds. In this situation, protected crops grown in springtime are foci for pest multiplication -foci from which the pests invade field crops in the summer. In the case of *T. vaporariorum*, this invasion usually takes place in El Maresme (NE of Spain) at the end of June or beginning of July.

A system of pest control for early protected tomato crops is at present being introduced commercially into El Maresme, based on the use of *Encarsia formosa* Gahan and selective pesticides (11) Unfortunately, *E. formosa* populations do not develop successfully under field conditions and are lost once the pest leaves the glass house (10). This situation led our group to consider another aphelinid which has been detected under field conditions in Mediterranean areas - *Encarsia tricolor* Foërster - with a view to the possibility of favouring the control of whitefly in field crops during the summer.

This paper deals with a review of the biological features of *E. tricolor* which are already known. The latter are compared with those of *E. formosa* in order to assess the potential of *E. tricolor* as a biological control agent. Finally, we report on the present state of our research and point to some future trends within it.

1.2. Biological features of Encarsia tricolor

E. tricolor is a facultative autoparasitoid which exists spontaneously in Mediterranean countries like Spain (1), France (14) an Italy (5). Females develop as primary parasitoids on several species of Aleyrodidae whereas males develop as hyperparasitoids of their own species or a different one like *E. formosa* (20).

There are few references on the biological features of *E. tricolor* since Stüben carried out the first works on this species (24). The studies carried out so far have dealt with longevity at 22 ºC (12), duration of development in the 20 - 30ºC range (12, 25) and the temperature threshold for searching behaviour and oviposition (18). Our group has studied the development of males and females (7), longevity at 24ºC on different host densities (3), fecundity and rate of egg maturation at 14-24ºC (non-published data), duration of the development in the 14-34ºC range (8), daily fecundity at different host densities and the functional response (5). Some experimental work on early tomato crops in glasshouses was also carried out (1). Several papers deal with field populations on different hosts in Italy (4, 6, 28)

There is much more information available on *E. formosa*. Quite a large number of research projects have been carried out in several countries and its widespread use in the Centre and North of Europe is well known (17, 27). Although different *E. formosa* populations have been used, all of them appear to be nearly identical to the maternal one from the United Kingdom (21). A selected summary of data from the literature on both species is presented in Table 1.

1.2.1. Longevity

E. tricolor longevity has only been studied in the 22 - 24ºC range. It is greatly influenced by host density, probably due to the effect of the latter on the amount of honeydew present on the leaves. In this temperature range, *E. tricolor* longevity is similar to that of *E. formosa*.

1.2.2. Fecundity and searching behaviour

In the light of our results, *E. tricolor* fecundity was found to be greater than that reported in earlier work on this species (13). In our experiments, *E. tricolor* females were only given access to hosts suitable for the development of females. Thus, all the eggs laid are assumed to be females. Females were only exposed to the test temperature for nine hours -the first hour without hosts and the remainder in the presence of the hosts. The mean number of eggs laid increased with temperature from 14 to 24ºC. It is rather difficult in this case to compare with *E. formosa* data, due to the different experimental conditions, which are summarized in Table 1. In our experiments *E. tricolor* females were exposed to the hosts for 8 hours, and the rest ot the time stayed at 24ºC. We can therefore assess the capacity of *E. tricolor* to search for the host and parasitize it, but not the effect of temperature on the rate of egg maturation. This point is now being investigated.

The temperature thresholds for displaying host searching and oviposition behaviour are similar for both species (about 12ºC, 18). Large differences in handling time were observed, but these did not affect daily oviposition rate. These *Encarsia* species being synovigenic, the limiting factor is more likely to be the rate of egg maturation.

Functional response has also been investigated, taking into account the age of the female and for the whole lifespan of the adult female. The curve that best fitted the data was Holling's type II. The instantaneous rate of attack and the handling time increased with the age of the female (Table 2,(3)).

1.2.3. Duration of development

The duration of development from egg to adult of *E. tricolor* females is shorter than that of *E. formosa* at temperatures lower than 22ºC. From data in Table 3 *E. formosa* seems to have a higher developmental threshold than *E. tricolor*. In order to predict the rate of development of *E. tricolor* under fluctuating temperatures, second degree polynomials give the best predictions (8) and we believe that they can be used in glasshouse conditions.

1.2.4. Glasshouse experiments

The only experiment of biological control of *T. vaporariorum* using *E. tricolor* was carried out on tomato crops sown in March and harvested right through until August (1). *E. tricolor* was introduced as parasitized *T. vaporariorum* nymphs three times during the growing season. The number of parasitoids that emerged came to a total of 7.7 per plant. The levels of parasitism observed were quite high during the whole growing season and a low percentage of plants infested with honeydew together with a very good harvest where observed when the crop was removed. These results encourage the use of *E. tricolor* in these early crops.

Table 1: Fecundity (F, number of eggs laid or parasitized hosts recovered per female) and longevity (L, days) of *E. tricolor* (E.t.) and *E. formosa* (E.f.) at different constant temperatures (T, ºC). Nr is the number of the reference, Nh is the number of hosts daily exposed to the parasitoid female, DOP is the duration of the oviposition period (h), Tr is the temperature at which the females were kept the rest of the time (ºC) and NDO is the number of days that the experiment lasted. np means non-published data.

	E.t.		E.f.						
T	L	F	L	F	Nr	Nh	DOP	Tr	NDO
14	--	40.8	--	---	np	50 N4	8	24	20
15	--	--	47.7	75.8	16	?	?	?	?
17	--	--	--	165.6	26	?	24	17	20
18	--	--	17.8	69.0	19	40 N4	24	18	unt. death
18	--	--	22.5	223.0	13	Abundant	24	18	30
18	--	90.6	--	---	np	50 N4	8	24	20
22	--	--	14.6	160.2	19	40 N4	24	22	unt. death
22	37.0	193.0	--	---	12	? N2	24	22	unt. death
24	25.4	103.1	--	---	?	20 N4	24	24	unt. death
24	--	113.7	--	---	np	50 N4	8	24	20
25	--	---	--	59.5	16	?	?	?	?
25	--	---	36.8	442.2	2	36 N4	24	25	unt. death
27	--	---	11.4	91.1	19	40 N4	24	27	unt. death
30	--	---	---	23.0	16	?	?	?	?
32	--	---	---	23.1	14	30 N4	24	32	unt. death

Table 2: Parameters of the Holling's type II functional response of *E. tricolor* females. a'= searching efficiency, Th = handling time (the unit of time is 48 h), n = number of replicates

	FEMALE AGE (DAYS)			
	1 - 48	1 - 10	11 - 20	20
a'	0.432	0.516	0.844	5.23
Th	0.033	0.009	0.040	0.468
R^2	0.483***	0.747***	0.594***	0,000
n	596	186	216	190

Table 3: Developmental period (days) of *E. tricolor* and *E. formosa* at constant temperatures (T). Figures in parenthesis are the number of the reference.

T	E.t.	E.f.
14	51.7 (8)	--
15	--	52.0 (15)
16	39.6 (8)	--
17	--	32.0 (22)
18	30.5 (8)	34.0 (23)
20	24.9 (8)	29.0 (22)
22	20.0 (8)	18.4 (14)
24	18.0 (8)	--
25	--	15.9 (2)
27	--	15.0 (23)
28	14.3 (8)	--
30	14.9 (8)	14.3 (15)
32	15.9 (8)	13.0 (22)
34	dead	--
35		14.0 (22)

1.3. Potential of *Encarsia tricolor* in IPM programmes

Protected vegetable crops in Spain are subject to different climatic, technological and cropping-system conditions. In these situations, it is very difficult to define suitable characteristics for natural enemies to be used in IPM programmes. The response of a parasitoid to be used for whitefly control with respect to temperature has to be considered in two situations - when temperatures are below 20ºC (autumm and winter protected crops in the South of Spain) and when they ar above 30ºC (ocurring for several hours in Mediterranean protected crops during late spring and early summer (1,9)).

E. tricolor develops faster than *E. formosa* at temperatures below 22ºC (Table 3) and faster than *T. vaporariorum* at temperatures above 15ºC (8). At low temperatures, *E. tricolor* is able to search for the host and lay a mean of 40.8 eggs (at 14ºC), if exposed eight hours to the host. Although we have not yet determined the rate of egg maturation at these low temperatures, we beleive that *E. tricolor* has a development duration and a fecundity which do not allow us to preclude the possibility of *E. tricolor* having a significant effect on *T. vaporariorum* populations at low temperatures.

Moreover, *E. formosa* is able to develop at temperatures at which *E. tricolor* larvae and pupae died (T 32ºC). It seems, therefore that when temperatures are high in the glasshouse *E. tricolor* can not be useful.

There are no great differences between *E. tricolor* and *E. formosa*'s duration of development end fecundities at temperatures around 24ºC, except for Arakawa's results (2), which are clearly beyond the range of other *E. formosa* fecundities reported.

1.4. Present and future research into *E. tricolor*.

We believe that the abovementioned considerations support the possible use of *E. tricolor* in IPM programmes on tomato crops, although some aspects need further investigation.

Our present research focuses on the study of *E. tricolor* fecundity and rate of egg maturation at low (10 - 20ºC) and high (28ºC) temperatures, the effect of different pesticides on adult and pupal mortality in *E. tricolor* and the study of sex allocation and sex ratio determination.

We focuse on the study of sex ratio because of the particular manner of reporoduction in *E. tricolor* which we have already mentioned, in an attempt to discover the influence of this type of reproduction on IPM programmes. Several hypotheses trying to explain or justify it have been prposed (7, 29).

E. tricolor is likely to be more difficult to mass rear than *E. formosa*. This is one more reason for studying the sex ratio, in order to predict the optimal sex ratio to be released in the glasshouse or in the field.

It is extremely difficult to predict the behaviour of *E. tricolor* in field conditions in summer cultivated crops, and this must be subject for further research. However, we may mention here that high percentages of parasitism have been observed in areas not heavily sprayed with pesticides.

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POSSIBILITIES FOR PROTECTION OF BIOCOMPONENTS AND THEIR REPRODUCTION IN BIOCENOSIS OF THE GLASSHOUSES BY INTEGRATED CONTROL

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SUMMARY

Choice and utilization of selective pesticides in the system for integreated control of diseases and pests on vegetable crops grown in glasshouses provide a possibility for reproduction of the predatory mite Phytoseiulus persimilis A.-H. used in the biological control of Tetranychid mites.
At the end of its period of economic effectiveness the predatory mite grows in number reaching the ratio 1:0.5 against its victim. Part of the reproduced prodatory mite can be gathered again and introduced in newly contaminated centres of Tetranychid mites. Application of the integrated system for biological control in glass houses provides conditions for the occurrence and multiplication of predators whose density plays a significant part in keeping low the number of Tetranychid populations. The species Ostearius melenopygius, Oligota oviformis Caey and Acaroletes tetranychorum Kieff multiply in relatively greater number in the glasshouses in Bulgaria.

1.1. INTRODUCTION

The repeated chemical treatments of glasshouse's crops against diseases and pests not only checks multiplication but also the occurrence of useful entomofauna in the biocenosis of glasshouses. Moreover even the colonized predatory mites, whose economic effectiveness is proved, are killed by next chemical treatment against the glasshouse whitefly (Atanassov, 1977).

With exploitation and introduction of the integrated system for control of diseases and pests on glasshouse's crops in Bulgaria is possible to protect the colonized bioagents as well as their reproduction (Atanassov et al., 1983). Favourable conditions for the occurrence and multiplication of several useful species in the colonies of glasshouse pests were created.

1.2. DESCRIPTION

With the reapeted experiments for testing the effectiveness of Phytoseiulus persimilis Athias-Henriot against the Tetranychid mites within the system of integrated control we found out some regularities of its reproduction. Results in Table 1 show that reproduction of the colonized predatory mite is conditioned not only by the climatic factors and the use of selective pesticides but also by the density of Tetranychid mites.

For example. at the average density of 60 mites per leaf of cucumbers and ratio 1:10 Ph. persimilis reached the maximum reproduction density on the 10th day after its colonization while at 1:20 that maximum is obtained on the 15th day and at 1:30 on the 20th day. In all cases however the maximum reproduction density is obtained after the descending gradation in preys dynamics-the Tetranychid mites-started. Analogous to these results is the data obtained by Pralavorio (1975).

Table 1. Reproduction of Ph. persimilis released at different ratio against the Tetranychid mites on cucumbers

Ratio	Preliminary density	Registered density of Ph. persimilis after... (days)				
		5	10	15	20	25
1:10	6	7.5	12	8	4	-
1:20	3	3.6	14.2	32	16	3
1:30	2	3	6	12	26	18

It was also found that at the moment of maximum reproduction density of Ph. persimilis its correlation to the Tetranychid mites is 1:0.5. That is the period we recommend as most suitable for gathering part of the colonized prodatory mite and for additional inner colonization of the freshly contaminated with mites plots. This method has a multiplication effect and it is successfully applied in the glasshouses in the village of Banja and Purvomai, the district of Plovdiv (Atanassov et al., 1983).

Having reduced to minimum the population of the Tetranychid mites predatory mites gather on the upper leaves and migrate to other plants. They can survive about 2 weeks without their usual animal food and after that they die. It is interesting to note that the predatory mite colonized 5 years ago in the flower glasshouses in Gorubljane can be found even now in the populations of Tetranychid mites on calla.

In the glasshouses where the integrated control has been carried out for 3 years occurred and multiplied to a relatively great numbers severall useful species some of which were new for the Bulgarian fauna. There were established the following species: Ostearius melenopygius, Oligota oviformis Casey (Staphylinidae), Acaroletes tetranychorum Kieff (Cecidomyidae), Acaroletes sp. and some other spider species that were not determined. Moreover out of the pupae of A.tetranychorum were isolated parasites that have not been identified either.

In trial plots of the glasshouse at the Institute for Plant Protection (Bulgaria) along with investigations on multiplication dynamics of the Tetranychid mites on various hosts there was studied the occurrence and multiplication of both specialized predatorys of the Tetranychid mites Oligota oviformis and Acaroletes tetranychorum.

From the data in Table 2 can be seen that the predators occur in June and their multiplication dynamics is parallel to that of the Tetranychid mites. The maximum density of A. tetranychorum was obtained in June 24 and that of O.oviformis on august 3.

Table 2. Occurrence and multiplication of predators in the glasshouse at the Institute for Plant Protection in 1984

Date	Average No of predators per leaf			
	A. tetranychorum		O. oviformis	
	larvae	pupae	larvae	adults
13 VI	0.4	-	-	-
23 VI	1.5	0.2	0.6	1
3 VII	2	1	3	2
13 VII	3.6	4	3.8	2.2
24 VII	1	6	4	3.1
3 VIII	0.8	4	5.4	2.6
13 VIII	-	3	1	-

In 1983 and 1984 A. tetranychorum occurred in the glasshouses at the village of Banja too. In the centres of serious infestation of cucumbers by the Tetranychid mites where their density ranges between 40 to 100 mites per leaf this species multiplied to 10 larvae per cucumber leaf. In the samples that we took at our visits at the glasshouse we registered up to 30 pupae of A. tetranychorum per leaf by the end of June and the beginning of July.

The occurrence of some spider species was massive, some of them catched adult whiteflies in their webs, others were specialized predatorys of the Tetranychid mites characterized by long life - time and high consumer ability. There also occurred some indifferent species like honey bees and others.

This shows that with the integrated control in the glasshouses there are created favourable conditions for the occurrence and multiplication of useful species which at certain conditions can play significant part in maintaining the glasshouse pest populations at low numbers. It is necessary to keep under observation their occurrence and density so that measures can be adopted for their protection.

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ATTACK SUCCESS OF *Amblyseius mckenziei* AND THE STAGE RELATED DEFENSIVE CAPACITY OF THRIPS LARVAE

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Abstract

Observations on predatory behaviour of Amblyseius mckenziei *Schuster & Pritchard (Acari:Phytoseiidae) showed that hungry predators are more successful than well-fed ones in seizing first stage larvae of their prey,* Thrips tabaci *Lindeman (Insecta:Thripidae). Second stage prey larvae, on the other hand, were seized with very low chance irrespective of the predator's state of starvation. This prey-stage related difference in attack success is at least partly due to the differential ability by the prey stages to counter a predator's attack. Detailed behavioural observations showed that second stage prey larvae defend themselves effectively by repeated abdominal jerks upon contact with a predator. Moreover, it was observed that in response to attack* T.tabaci *larvae produced fecal droplets, which caused the predator to withdraw and clean itself.*

Introduction

Thrips tabaci Lindeman is a common pest of sweet pepper and cucumber crops. Biological thrips control seems possible by introduction of two phytoseiid predators: *Amblyseius cucumeris* Oudemans and *Amblyseius mckenziei* Schuster & Pritchard (Ramakers, 1978; Ramakers & v. Lieburg, 1982). The former species is now commercially applied in sweet pepper crops (de Klerk & Ramakers.1986). On cucumber crops, however, biológical control of thrips has not yet been achieved. To evaluate their capacities to control *T. tabaci* on cucumber, both phytoseiid species were studied in the laboratory at the individual level. This paper discusses one aspect of the predator-prey system under study: the capture success ratio , henceforth denoted as CSR. It is defined as the fraction of predator-prey encounters that results in the predator's killing and eating the prey. An encounter is an event in which a predator contacts a prey larva with its first pair of legs or its pedipalps. According to Fransz (1974) and Sabelis (1981) the CSR of phytoseiid predators is related to their satiation level. A well-fed predator is less motivated to seize a prey than a starved one. But the predator's motivation is not the only determinant of what fraction of encounters will result in ingestion and death of the prey. If the prey can counter predator attacks, the CSR is determined also by the prey. The CSR is, therefore, the result of a complex of factors including the predator's feeding state and the prey's defense. Preliminary observations of attack success by *A.cucumeris* (de Klerk,1984) and *A.mckenziei* (Bakker, unpublished) suggested that the capacity of thrips larvae to counter an attack probably depends on their body size and/or developmental stage. Here we report on studies of *A.mckenziei* only.

Methods and materials

All experiments were carried out with female predators that were in the oviposition phase. These have the highest energy demands of any predator stage.

Females of *A.mckenziei* have a high and constant daily egg production that (at high temperatures) equals their own body weight (Bakker,in prep.). Because of the high and constant rate of food conversion we assume that the predator's motivation is fully determined by its satiation level and not by its age.
To standardize the satiation level, the predators were first observed until they killed a prey larva, and then put into small plastic tubes (0.4 cc.), where they were deprived of food and water for a predetermined period, further referred to as t, at 25°C. At the start of each experiment the tube was placed on a 5 cm^2 cucumber leaf disc until the mite walked out onto the disc. The leaf disc was infested with 20 larvae of *T.tabaci* 24 hours before predator release. The larvae were either early first stage (4.5 ± 1.8 μg;n=30) or late second stage (16.3 ± 2.9 μg;n=30). A Sartorius electro ultramicro balance was used to determine these weights.
From the moment the predator walked out of the cage onto the leaf she was continuously observed until she killed a prey larva, and if not, she was observed for a maximum of three hours. During these behavioural observations all contacts between predator and prey were recorded. For each deprivation time-class (t-class) then the fraction of successful encounters out of all predator-prey contacts was calculated. Because the gut of phytoseiids is emptied exponentially (Fransz,1974;Sabelis,1981), the success ratios were classified on a logarithmic time scale.
To investigate the role of the prey's active defense on the CSR the experiments were repeated with immobilized second stage larvae that were anesthetized with CO_2. Here predators were used with t>15 hours.

Results

The data are presented in Table 1 and graphically in Figure 1. For predators encountering first stage larvae the CSR-curve is sigmoïd. Below t=8 hours first stage larvae are encountered with low chance of capture, whereas above t=11 hours they incur high risk of being killed after contact with a predator. The CSR's for t<8 and t>11 differed significantly at the 0.001 level (binomial test for differences of proportions).
Second stage larvae appear to be hard to capture. The CSR increases from 0 % at t<8 to 3.8% at 14<t<19. The CSR's at these t's were significantly different at a 5% level.

As mentioned before, the CSR results from a combination of predator and prey factors. Since in both experiments the predator's condition was equal, the differences in CSR must be attributed to the stage of the prey. Behavioural observations showed that when touched by a predator all stages of *T.tabaci* react by jerking their abdomen. First stage larvae, however, are less fierce with their jerks than second stage larvae (see discussion). Crespi (1986) also described this behaviour for *Hoplothrips pedicularius*, a colonial thrips, where it is a component of the males' behaviour in their fight for mates. He coined the term 'wagging' to describe this behaviour, which we shall adopt. With *T.tabaci* this 'wagging' usually coincides with the production of a drop of rectal fluid from the anus. The latter phenomenon was mentioned also for other thrips species (Lewis,1973). Most (if not all) successful encounters with second stage larvae occurred when the predators grasped the prey in the thorax region. In this way the predator avoided the thrips' abdominal jerk.
To elucidate whether the second stage's wagging and fluid production are elements of the thrips' defense system, experiments were designed in which hungry predators (t>15) were offered CO_2-anesthetised second stage larvae. These larvae were killed and eaten in 47 out of 240 encounters, whereas, as shown in Table 1, untreated larvae were eaten in only 9 out of 593 encounters. These ratios differ significantly at the 0.001 level (binomial test for differences of proportions). Thus, blocking the defense system of second stage larvae resulted in a 13-fold increase of the CSR (see dotted line in Figure 1).

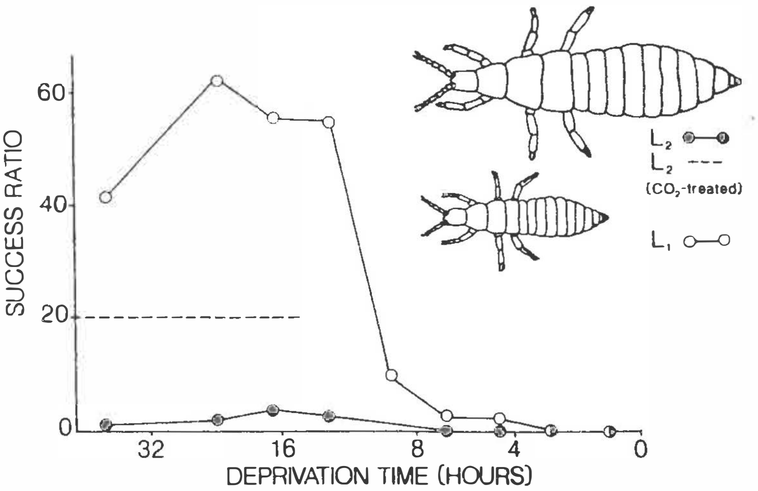

Figure 1. The relation between capture success ratio (CSR) and the duration of pre-test food and water deprivation for *A.mckenziei* females placed on leaf discs with either first or second stage larvae of *T.tabaci*.

Table 1. Capture success ratio (CSR) for *A.mckenziei* females encountering either first or second larval stages of *T.tabaci* at various predator satiation levels (t-classes). Because the gut is emptied exponentially (Fransz,1974;Sabelis,1981) the capture success ratios are classified on a logarithmic time scale.

	First stage larva		Second stage larva	
t-class (hrs)	Encounters	Success ratio (%)	Encounters	Success ratio (%)
0 - 1.5	208	0	94	0
1.5 - 3.5	98	0	111	0.9
3.5 - 5.5	48	2.1	19	0
5.5 - 8	86	2.3	49	0
8 - 11	21	9.5	-	-
11 - 14	29	55.2	110	2.7
14 - 19	18	55.6	53	3.8
19 - 25	11	63.6	241	1.7
25 - 36	-	-	45	0
36 - 48	12	41.7	254	1.2

Discussion

Our experiments showed that second stage larvae are killed and eaten less frequently than first stage larvae upon contact with a predator. Both first and second larval stages respond to predator contact by wagging, but this defense is obviously less effective with regard to the first larval stages. Observation clearly showed that the wagging of second stage larvae was more frequent, pertinent and severe than that of the first stage larvae. That wagging behaviour and the production of fecal droplets comprises an important part of the second stage's defense, was illustrated by the fact that immobilized second stage larvae were eaten at a significantly higher rate than were active second stage larvae. Because immobilized second stage larvae were not as preferred as active first stage ones, there must be other reasons for the observed difference in capture rate with first and second stage larvae. Two reasons are conceivable: (1) the anesthesia made the prey less attractive, and (2) other factors are

involved, such as food quality and/or thickness of the cuticle relative to the minute length of the predators' piercing mouth parts.
The difference in attack success rate with first and second stage prey larvae may have consequences for the biological control of *T. tabaci*. Because there is only one stage in the life cycle of this pest that is substantially vulnerable to attack by predatory mites, and because the age distribution of the thrips population is not stabilized, especially early in the growing season, the suitable prey stage (first stage larvae) may not be available when predatory mites are present (introduced) early in the season. Moreover the numerical response of the predator may be hampered due to the low mobility of the predators' juvenile stage. Therefore it is of crucial importance that the mite population be sustained by alternative food when first stage thrips larvae are unavailable.

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POSSIBILITIES OF NON-CHEMICAL CONTROL OF LIRIOMYZA TRIFOLII (DIPTERA:AGROMYZIDAE) IN POLAND

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Summary

The paper presents some results of studies conducted at the Section of Methods of Plant Control at Agricultural University in Poznań on possibilities of non-chemical control of Liriomyza trifolii in Poland.Experiments showed that pupas of the pest are attacted by very few parasites,the main being Diglyphus isaea (Walk).The highest death rate of pupas was observed when they were covered by 20 cm layer of soil and when they were exposed to temperature - 3°C for at least one day.

1.1 Introduction

Liriomyza trifolii was brought to Poland at the end of seventies with seedlings of chrysanthemums and gerberas imported from the Netherlands (Baranowski 1981).Since then this species has become the main pest of plants grown in glass-houses and plastic tunnels because of serious problems with its control. Studies on biology and control of Liriomyza trifolii in Polish conditions have been carried out since 1980 at the Section of Plant Protection at Poznań Agricultural University.

In experiments on possibilities of non-chemical control of Liriomyza trifolii the following were determined:
-number and species composition of the parasites
-influence of depth of pupa covering on hatching of mature insects
-effect of low temperature on survival of pupas and hatching of mature insects
-susceptibility of chrysanthemum cultivars to Liriomyza trifolii attack

1.2. Methods

In order to determine the number amd species composition of parasites of Liriomyza trifolii,larvae leaving leaves were collected,put into test-tubes and placed in a breeding chamber. Hatching parasites were caught and sent to be assayed.

Experiments on the influence of depth of pupa covering on hatching of mature insects were conducted in laboratory using high glass cylinders.Petri dishes were filled with soil and 100 pupas were placed on each.Next they were covered with soil to the depth of 2,5,10 and 20 cm.Hatching mature insects were counted.

Research on the effect of temperature on development of pupas was carried out in air-conditioned chambers of the Polish Academy of Science in Kórnik.200 pupas were placed in a chamber with the required temperature where they were kept for a definite period of time.They were then tranferred to a chamber with temperature + 25°C.Hatching mature insects were counted and death calculated.

Studies on susceptibility of various cultivars of chrysanthemums to attack by Liriomyza trifolii were conducted in 1984 and published (Baranowski,Dankowska 1986).For this reason this paper will only present summaries of results obtained.

1.3.Results

From several thousand cultures grown for a number of years only the following 7 parasites were collected:

Diplyphus isaea (Walk)	- 3	(Eulophidae)
Gnamptodon pumilio (Nees)	- 2	(Braconidae)
Opius sp.	- 1	-"-
Rhizarcha lestes (Nix)	- 1	-"-

It is evident from the above data that larvae of Liriomyza trifolii have very few natural enemies and consequently any plans to employ biological methods of control would have to provide for introduction of parasites entirely from artificial cultures.

Table 1 presents results of experiments on the influence of depth of pupa covering on hatching of mature insects.

Table 1

Influence of depth of pupa covering on hatching of mature insects

Depth of covering	Number of pupas	Number of mature insects		Total	Death rate %
Control	100	23	18	41	
2 cm	100	9	11	20	51,0
5 cm	100	7	4	11	73,0
10 cm	100	2	-	2	95,1
20 cm	100	-	-	-	100,0

It is clear from the table that even 5 cm layer of soil reduces considerably hatching of mature insects resulting in 75% death rate,while 10 cm layer of soil resulted in 95 % death rate. For practical purposes,ploughing to the depth of 20 cm may be recommended.

Results of research on the effect of temperatures on the development of pupas are shown in Table 2.

Table 2

Effect of temperature on pupa development

Temperature °C	Time of exposition days	Number of hatched pupas	Sex index		Death rate %
-3	1	9	6	3	87,14
-3	7	8	4	4	88,57
-3	14	9	5	4	87,14
+3	7	24	12	12	65,71
+3	14	22	15	7	68,57
+10	10	69	32	37	1,43
Control +25		70	37	33	

It is evident that temperature +10°C did not cause significant reduction in hatching of mature insects.Markedly higher death rate was observed already at temperature +3°C.When pupas were kept at temperature -3°C death rate was quite high. However,time of exposure to various temperatures did not affect death rate significantly.At temperature -3°C and time of exposition 1 day death rate of pupas was the same as when they were kept in this temperature for 14 days. This fact is of significant practical importance since, in Polish conditions, because of fuel shortage, glass-houses are frequently not heated during winter.

Investigations on susceptibility of chrysanthemum culivars to attack by Liriomyza trifolii revealed that there are no cultivars which would be completely resistant (Baranowski, Dankowska 1986). However, such cultivars as Bornholm and Bornholm Bronze were less damaged by the pest. Spray type cultivars were attacted more often than standard ones. Proper selection of cultivars for cultivation may considerably help reduce infestation with Liriomyza trifolii. It was also noted that chemical control of the pest is more difficult on cultivars susceptible than on less susceptible.

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THE EXPERIENCE OF BIOLOGICAL AND INTEGRATED CONTROL OF PESTS ON GLASSHOUSE CROPS IN THE USSR

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The glasshouse vegetable crops grown in the USSR are damaged by a number of injurious mites and insects. The most significant of these are two-spotted spider mite (Tetranychus urticae KOCH), carmine spider mite (T. cinnabarinus BOISD.), melon aphid (Aphis gossypii GLOV:), potato aphid (Aulacorthum solani KALT.), lettuce aphid (Macrosiphum euphorbiae THOM.), and other species of aphids as well as whitefly (Trialeurodes vaporariorum WESTW.), tobacco thrips (Thrips tabaci LIND.), and others.

Chemical control, which is still being employed at present, has many well-known disadvantages. In this connection, of great interest is biological control that is playing an increasingly important role in plant protection.

The predatory mite, Phytoseiulus persimilis ATH.- HENR., which was introduced into the USSR in 1963, occupies more than 3,600 ha every year (Nikonov, 1986). The technique of mass rearing and utilization of this predator, devised by Beglyarov (1968) and supplemented by Bondarenko (1974) and other investigators, has proved effective, cheap, and accessible for glasshouse vegetable producers.

Much effort has been made in search for effecitve aphidophages (Bondarenko, 1979). However, at present only two species: the predatory gall-midge, Aphidoletes aphidimyza ROND., and the green lacewing, Chrysopa carnea STEPH., are applied in practice for biological kontrol. Important advantages of the gall-midge are: its ability to propagate in greenhouses throughout the whole season as long as there is food and even to hibernate in the soil surface layer; its activity at nights, when the air temperature is more favourable; and its good retention on leaves of cucumbers, peppers, and many kinds of ornamentals. The hig selectivity of A. aphidimyza females during oviposition is especially of great importance: they do not even miss the plants with single aphids (El Titi, 1973; Bondarenko and Asyakin, 1975b).

The technique of rearing gall-midges on a natural diet has proved to be simple (Bondarenko and Asyakin, 1975a) and it is used by a number of industrial laboratories in the USSR. As a result, the range of gall-midges introduction has come up to 68 ha in 1985 and will be expanding further on.

Detailed studies of conditions for hatching and for overcoming diapause (Bondarenko et.al., 1979) solved the problem of prolonged storage of the gall-midges thus enabling biofactory work on its development and accumulation the whole year round. The emergence rate of adults 6 months after the beginning of diapause in gall-midge larvae in cocoons was 87,6 %, and 74,3 % after 12 months (Bondarenko and Moiseyev, 1982). Objective criteria for controlling the quality of the gall-midge population during its continuous mass rearing were also proposed (Bondarenko and Kozlova, 1982).

For effective application of the gall-midge to cucumbers a ratio of 1:5 larvae of predator to prey is required. Sometimes a ratio of 1:9 can be successful when aphid colonies are small while relative air humidity in the greenhouses is more stable and exceeds 70 per cent. When releasing gall-midges in the pupal stage, one cocoon is needed for 1 or 2 aphids and according to the data by Markkula and Tiittanen (1977) 3 cocoons for 10 aphids, which seems also to depend on the glasshouse design and microclimate. Gall-midges may be released on greenhouse crops not only in cocoons but also as the second instar larvae suspended in water (Asatur et al., 1985).

One of the important advantages of gall-midges is the possibility of collecting and transferring accumulated imagos from one glasshouse to another. In 1985, 0.5 ha under tomatoes were protected by this method from peach aphid.

Sweet pepper is usually produced in glasshouses from January till November. To prevent the diapause of larvae in spring and autumn, one can apply extra lighting ut to 18 light hours daily, taking care that the illumination should reach at least 5 lk (Bondarenko and Ermolayev, 1985).

The green lacewing cannot multiply in vegetable greenhouses. Therefore it has to be used for inundative release, i.e. as "living insecticide". For example, a one or two-fold release of the second instar larvae with a two-week interval, giving an initial ratio of predator to prey of I:20, I:26 or in some cases I:50 allowed control of aphids on mangold and celery at the end of the season (Bondarenko and Moiseyev, 1972; Moiseyev et al., 1972). Good results were also obtained when green lacewing larvae were applied on radish, Chinese cabbage, parsley, dill, and other green vegetables (Beglyarov and Ushchekov, 1977).

In spite of favourable result obtained in tests with some insects of Aphidiidae family (Hofsvang and Hagvar, 1982), they may be considered only as minor aphidophages in glasshouse conditions. Aphidiidae are highly selective in their food, prone to superparasite attacks, and poorly stored when mass-reared.

The problem of vegetable crop protection against the whitefly is of the greatest importance in glasshouses of the USSR southern districts. In Great Britain, its parasite, Encarsia formosa GAH., is successfully used against this pest in more than 30% of the greenhouse area under tomato (Gould, 1980). The volume of its application on this crop in the Netherlands is similar; however, attempts to utilize Encarsia in cucumbers have failed (van Lenteren and Woets, 1977). In two-year farm trials conducted by Popov and Zabudskaya (1983) in glasshouses of Slobodzeisky district in Moldavia on the area of 5,000 m^2, Encarsia has proved to be rather effective in cucumbers, too. In 1984 Encarsia was released in the USSR on the territory of 37,.5 ha (Beglyarov, 1985).

In controlling tobacco thrips in the USSR the predatory mite Amblyseius mckenziei SCH. et PR. is increasingly applied. Field test made by us in 1983 on the population received by N.A. Popov from Dr. P. Ramakers (the Netherlands) showed its high efficiency. Two- or three-fold colonization of this predator gave the opportunity to suppress the multiplication of the pest before the final stage of cucumber vegetation period on two farms of the Leningrad region on the territory over 2.5 ha. Technical recommendations concerning mass rearing of this mite are published (Beglyarov and Suchalkin, 1985).

Beglyarov has also published (1985) the results of application of microbiological means for controlling pests and protected ground diseases in the USSR. We may add that for root rot control in greenhouses trichodermin is applied on the area of 2,800 ha, while tomato vaccination with the weakened strain of tobacco mosaic virus is used on the territory of 1,700 ha (Nikonov, 1986).

In conclusion, it should be noted that phytoseiulus applied on most farms of the firm "Leto" near Leningrad makes it possible to obtain more than 3/4 of the cucumber yield without the help of acaricides on the territory over 100 ha with reduced rotation. The extent of combined acariphages-entomophages application in the biological and integrated control is gradually incerasing, too. Thus, in 1985, on two greenhouse farms of the Leningrad region use of predators helped to protect from spider mites, aphids, and tobacco thrips 13.8 ha of greenhouse ground, of which quantity 4.0 ha (3 ha under cucumbers, 0.5 ha under tomatoes, and 0.5 ha under sweet pepper) received no insecticide or acaricide treatment at all, and the rest 9.8 ha - only one treatment over the season.

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BIOLOGICAL CONTROL IN PROTECTED CROPS IN NORTHERN ITALY'S PO VALLEY

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Summary

Biological Control in Protected Crops: Situation in Emilia-Romagna Region. This program was started in 1983. Experimental and pilot trials include these crops: strawberry, tomato, cucumber, eggplant and gerbera using *Chrysoperla carnea* (Stephens), *Encarsia formosa* Gahan, *Phytoseiulus persimilis* Athias - Henriot and *Diglyphus isaea* (Walker). Researches have been carried out on *Edovum puttleri* Grissel (Hymenoptera, Eulophidae), an egg-parasite of *Leptinotarsa decemlineata* (Say): key eggplant pest. Integrated Control has been applied to more than 7 Ha of protected crops. Since 1983, at an extention service Cooperative (Centrale Ortofrutticola alla Produzione di Cesena) a Natural Enemies Rearing Laboratory was set up with Regional Government funds. The Istituto di Entomologia " Guido Grandi" of Bologna University is in charge of the mass - rearing studies and of the experimental trials in greenhouse or in open field.

1.1 Introduction

In Emilia Romagna Region (Northern Italy), at Centrale Ortofrutticola alla Produzione of Cesena (Fruit and Horticulture Extention Service Cooperative), an experimental laboratory for the mass rearing of natural enemies has been set up with Regional Government funds. The " Istituto di Entomologia G. Grandi " of Bologna University is in charge of conducting the Scientific trials. Prof. Giorgio Celli's research group is studying improvement of mass-rearings of natural enemies and supervising the experimental and pilot trials in greenhouse and in open field. The Natural Enemies Rearing Laboratory is now producing *Chrysoperla carnea* (Stephens) and *Trichogramma maidis* Pint.et Voeg., and we are studying the egg-parasite of Colorado Potato Beetle (*Leptinotarsa decemlineata* (Say)) *Edovum puttleri* Grissel (Hymenoptera, Eulophidae) and the leafminer parasite *Diglyphus isaea* (Walker). Biological Control is being tested in commercial unheated plastic tunnels. Since 1985 pilot trials have been conducted to spread Biological Control techniques among the largest number of growers. *Encarsia formosa* Gahan and *Phytoseiulus persimilis* Athias - Henriot are supplied by Koppert Co. (Holland).

1.2 Strawberry.

This crop is very important in Emilia Romagna Region. We are using the predator *C. carnea* against aphids: *Macrosiphum euphorbiae* (Thomas) and

Chaetosiphon (Pentatrichopus) fragaefolii (Cock) (Celli et al., 1986). The trials areas to date are:

1983:	1 experimental greenhouse C. carnea	45 m^2
1984:	30 greenhouses without insecticides	9800 m^2
	4 experimental or pilot greenhouses C. carnea	913 m^2
1985:	46 greenhouses without insecticides	17160 m^2
	10 experimental or pilot greenhouses C. carnea	3584 m^2
1986:	98 greenhouses without insecticides	38500 m^2
	13 experimental or pilot greenhouse C. carnea	6180 m^2
	5 experimental greenhouses P. persimilis	2800 m^2

C. carnea is released as eggs ready to hatch on the oviposition card at onset of infestation (April). One release of 80 eggs/m^2 is sufficient to control aphids, resulting in a significative difference in comparison to controls. On strawberry C. carnea is very efficient because plants are touching and in contact with the plastic mulch. C. carnea also curbs secondary pests. Research in commercial greenhouses has showed that aphid infestation occurred in 10 to 20% of all greenhouses. Preventive sprays (Methamidophos, Thionazin) are therefore not indicated although growers normally use them. In 1986, we checked 98 greenhouses without insecticides or acaricides. In 52 there were Tetranychus urticae Koch infestation. In 50 of them, the natural predator P. persimilis was found to control the two-spotted spider mite. We are studying how to reduce the number of C. carnea eggs per m^2 and the influence of some fungicides on populations of T. urticae and P. persimilis.

1.3 Tomato.

E. formosa was released against Trialeurodes vaporariorum (Westwood) in unheated greenhouses. The pest occurs rarely in the spring crops, but it always attacks summer crops. We are studying the use of yellow sticky traps for monitoring whiteflies and how to determine the right moment for the first release. 4 fortnightlly releases are sufficient for good control (4 parasites/m^2 per release). Aphids (M. euphorbiae) are frequent during the spring. In Integrated Control, we advise Heptenophos because Pirimicarb is not completely efficient and, in Italy, it has a 14-day waiting period. During the summer high temperature and natural enemies prevent large outbreaks.

1985:	6 experimental or pilot greenhouses E. formosa	2500 m^2
1986	50 experimental or pilot greenhouses E. formosa	20800 m^2

1.4 Cucumber

A single P. persimilis release (5,5 predators/m^2) is used after the first pest has been seen. T. urticae is always present in spring crops, Biological Control is very efficient. In the same period we often have a thrips problem. Also here we can control Aphis gossypii Glover by Heptenophos.

1985:	2 experimental greenhouses P. persimilis	440 m^2
1986:	19 experimental or pilot greenhouses P. persimilis	5200 m^2

1.5 Eggplant

T. urticae and T. vaporariorum are usually a problem. P. persimilis (5,5 predators/m^2) and E. formosa (4 parasites/m^2 per release) provide good control but sometimes 4 parasites releases are not sufficient. In Integrated Control, aphids (Myzus persicae (Sulzer), M. euphorbiae) can be controlled by Heptenophos. We started the first experiment by releasing C. carnea eggs at the beginning of infestation. After this first period, natural enemies contribute a lot to contain aphids till the end of crops harvest. The most dangerous pest is L. decemlineata. At this moment we have not enough biological agents or selective insecticides against this pest. So, in 1986, we started our experiments with the egg parasite E. puttleri and the nematode entomoparasite Steinernema feltiae Filip. Initial results look encouraging.

1985: 3 experimental greenhouses E. formosa, P. persimilis 620 m^2
1986: 15 experimental or pilot greenhouses E. formosa, P. persimilis 6400 m^2

1.6 Gerbera

In northern Italy, this ornamental crop is normally cultivated in heated glasshouses. Liriomyza trifolii (Burgess) was recently found in Emilia Romagna Region (1984) in a few farms. E. formosa, P. persimilis and D. isaea seem able to control pests, only if we can start releases on young plants at the beginning of infestation. Big problems are secondary pests like Thrips, so we must resolve them to work out an Integrated Control strategy.

1985: 3 experimental greenhouses E. formosa, P. persimilis 2220 m^2
1986: 3 experimental greenhouses E. formosa, P. persimilis, D. isaea 1900 m^2

Final Chapter

- On certain crops, expecially in Mediterraneane Regions, the use of C. carnea could be interesting, if we are able to reduce mass-rearing costs.

- We need studies to evaluate the Thrips' predators because we have found during the summer season that they are able to control the pests on certain crops.

- Colorado Potato Beetle control agents must be studied singularly or in combination.

- In mediterranean regions, if we stop sprays, Natural Control becomes very important. So it would be useful to evaluate this potential and the possibility of better exploiting it.

- Soil sterilization is also a big ecological problem.

- We need disease-control programs where chemicals are used as less often as possible.

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Schedule, Northern Italy 1986

	Pests	Crops protection program experimental phase
STRAWBERRY 3.8 Ha	*Macrosiphum euphorbiae* *Chaetosiphon fragaefolii*	*Chrysoperla carnea*
	Tetranychus urticae	*Phytoseiulus persimilis*
TOMATO 2.1 Ha	*Trialeurodes vaporariorum*	*Encarsia formosa*
CUCUMBER 0.5 Ha	*Tetranychus urticae*	*Phytoseiulus persimilis*
EGGPLANT 0.6 Ha	*Trialeurodes vaporariorum*	*Encarsia formosa*
	Tetranychus urticae	*Phytoseiulus persimilis*
	Leptinotarsa decemlineata	*Edovum puttleri, Steinernema feltiae*
GERBERA 0.2 Ha	*Trialeurodes vaporariorum*	*Encarsia formosa*
	Tetranychus urticae	*Phytoseiulus persimilis*
	Liriomyza trifolii	*Diglyphus isaea*

PROGRESS IN DEVELOPING A CONTROLLED GLASSHOUSE ENVIRONMENT TO PROMOTE BIOLOGICAL PEST CONTROL

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Summary

We are developing a glasshouse computer control system to benefit biological pest control. This is concentrating on the parasitoids of glasshouse mealybug *Planococcus citri*. We have established a data base on the thermal requirements of development, egg production, searching and dispersal with particular reference to ornamental crops. Our computer control system, with reference to a strict energy budget, uses our biological data base to cycle heating and lighting to benefit biological pest control and calculate number and frequency of release of beneficials.

1 Development of Research

Glasshouse crops represent a large capital investment and high running costs. Computer control systems can offer significant savings in heating, lighting, CO_2 control and efficient ventilation. Current work on control systems is concerned largely with improving feedback mechanisms to produce the optimal control response (O'Flaherty, 1981). Glasshouse plant studies are concerned in quantifying the crop requirements in terms of nutrition, light, temperature and CO_2 to achieve the most economical environment (Damagnez, 1981). There is also work in progress on breeding new varieties with lower thermal requirements. Pest and disease control forms a significant component in management and running costs but hitherto has received little attention in glasshouse computer control systems (Tauber & Helgesen, 1978).

At Wye we have installed a computer controlled glasshouse facility which controls and records the heating and lighting of some 32 research cubicles including a large tropical plant collection. Altogether this comprises 1,400 square metres of glasshouse. The system is used almost exclusively to gather data for our work on pest control management. We have been studying the mealybug *Planococcus citri* (Risso), the mealybug predator *Cryptolaemus montrouzieri* (Mulsant) and the parasitoids *Leptomastix dactylopii* Howard, *Anagyrus pseudococci* (Girault) and *Leptomastidea abnormis* (Girault). Like the pests the control agents are tropical in origin. In our own glasshouses they give fair control in summer on many plants but their performance is erratic from autumn to spring. For several years we have made regular releases of parasitoids at several sites in Britain into interior plantings maintained at a maximum of 20°C. In general results have been disappointing. In contrast during 1986 we made weekly releases at four centres displaying tropical butterflies and according to the managers obtained excellent control on a variety of plants. Summy *et al* (1986) have recorded good control on glasshouse *Citrus* using these same parasitoids.

To account for these variable results we have investigated, in the laboratory, the thermal requirements of pest and parasitoids for development, egg production, adult longevity, dispersal and searching (Copland, 1983). One of our objectives is to develop a computer simulation model which can be integrated with the environmental control system to produce an environment which favours biological control, and advises on release dates and numbers of control agents.

1.1 Experimental method for temperature studies

While temperature has a critical part to play, the relationship with development and other biology is a complex and interesting one. Some workers have suggested that studies at constant temperature have little relevance to observed development under cycling regimes while others have disputed this (Howe, 1967). Our own experience suggests that over a range between about 18°C and 28°C the relationship with temperature is approximately linear. Studies at constant temperature can therefore be used to calculate day degrees and accurate estimates of development times can be computed in cycled regimes within these limits. However one of the features of glasshouse work is the extremes of temperature from very high in summer to low in winter. Constant high temperature studies show very high mortality while studies at constant low temperatures take too long and have high variance. If such thresholds derived from constant temperature experiments are incorporated into a model we find a poor correlation between observed and predicted results.

To overcome this problem we have studied development under cycled regimes of 12 h at a known optimum of perhaps 25°C and either 12 h at a low 10°C or 12 h at a high 35°C. Such work indicates that the adverse physiological effects of extreme temperatures may be readily reversed. We may suppose that one effect of the low temperature is to prevent active behavioural phases such as egg hatch, feeding, moulting, pupation and emergence although actual growth continues. Similarly, high temperature may lead to the build up of some metabolite which is removed during the return to optimal conditions. Temperatures cycled between the optimum and the extreme values usually give a much faster rate of development than one would expect from the constant temperature data. There is a problem of expressing this relationship because it will vary depending on how much and for how long the excessive conditions are maintained and the optimum with which they are cycled. We find that relationships calculated from a 12 h cycled regime offer an extremely good degree of accuracy for glasshouse work and may be represented by a 3rd or 4th order polynomial regression.

We have used these cycling techniques to study other factors which contribute to control success (Tingle, 1985). In general it would seem behavioural activity operates over narrow temperature limits so that dispersal and searching are efficient over a range of only about 22°C to 30°C. Oviposition and feeding require only a few hours daily above an activity temperature threshold for effective control. We find as many eggs are laid during a daily 5 h warm period as over a 24 h period. Similar observations were recorded by van Lenteren & Hulspas-Jordaan (1983) working on whitefly parasitoids.

Determining development time is easy but longevity and egg production depend on host finding and feeding. In practice we find quite short periods of heating are adequate. Dispersal and searching are difficult to study and even more difficult to simulate in a program. One method we have used is to study parasitoid movement and host finding in different size arenas ranging from small petri dishes through insect cages to the glasshouse cubicle. The relationship between performance in these different spaces and at different temperatures can be used to determine possible movement behaviour. In practice different levels of control are achieved on different plant species even when these are growing in close proximity and so the role of host plant is particularly important. Woets & van Lenteren (1976) showed searching patterns and efficiency are influenced by physical features of the plant such as hairiness and by chemical cues of the host.

We have found that we can account for poor performance on the basis of insufficent heat for crucial parts of the the biology. Raising glasshouse temperatures will improve control but the increase in fuel consumption is unacceptable. While energy constaints will determine a particular heating budget we can cycle these temperatures such that at least for some time during the day there is the opportunity for key temperature limited physiology and behaviour to take place. After this requirement has been met we may compensate for the energy used by dropping the temperature a degree or two for the rest of the day. Therefore within the glasshouse and the confines of a strict energy budget, cycled temperatures provide the key to improving biological control.

In addition, control is proportional to the number of predators and parasites which are introduced and increasing the number of introductions of beneficials may compensate for reduced efficiency. Up to a point this may be cheaper than raising the temperature.

1.2 Computer model

Most population models assume optimum conditions and seek to express the interrelations between predators, parasitoids and the host in relation to population densities and fecundity rates. Yet in our experience of glasshouse work, temperature is of overriding importance for all aspects of life, and the daily fluctuations present a complicated problem to analyse. Despite this, we felt it should be possible to break down the various components into many simple relationships with temperature and then devise a generalised simulation model which can be run on inexpensive and widely available microcomputers. The prime concern was to provide for flexibility of all parameters so that we could model many different species and readily alter the relative value of different components and the relationships between them.

BASIC is the language usually available on most microcomputers and we have used it for most of the program. The time taken to compute can often become severely limiting and so two approaches have been used. Small machine code routines have been developed to specifically cope with manipulation of arrays which simulate development and ageing processes. To minimise processing time, wherever possible tables of precalculated data are stored in memory. With this technique we have achieved a fair compromise between speed, accuracy and use of memory. The program is made up of a number of modules, described in more detail below.

1.2.1 Database

The database comprises precalculated tables of development, longevity, egg production, searching and dispersal in the range 0°C to 50°C in 0.2°C increments. The computer looks up in the table the relevant value rather than computing it. In addition there is a data file containing over 40 constants which define various parameters to do with the development and ageing process, factors affecting sex allocation, egg resorption, host marking and discrimination. Associated with the database are various file handling modules. These include routines for selecting the species which one wishes to include in the model, a program which calculates the best fit polynomial regression equations from laboratory and field data to produce the look-up tables, and one which manages the constant data files.

1.2.2 Setting up populations, plant and environmental factors

The program is able to set up any predetermined population of pest and several populations of competing parasitoids. The populations may be defined in sexed age classes from egg through to adult. The pest population can be distributed within patches of particular frequency and size over a square metre of leaf area. Plant types are defined with different suitability for pest growth and parasite searching. The program operates over any user defined regime of constant temperature, sine wave and block cycled temperatures or can use real hourly temperature records from the glasshouse. The model allows the user to define either new parameters each time, or a range of standard populations, or to restart from a previously interrupted simulation which had been saved to disc.

1.2.3 The simulation program

The model represents the lifecycle of each species by 100 elements of an array with 50 used for development from egg laying to adult emergence and 50 to represent adult longevity. The program models development of pest and parasitoid up to adult emergence, adult longevity, egg production, and resorption, searching on clean and infested leaves, dispersal, the effects of both host density and size, parasite density, host marking and discrimination, and their effects on oviposition, sex allocation and dispersal. Patch size and number are varied in response to pest numbers and dispersal characteristics which in turn determines the feeding, dispersal and egg production of the parasitoids. The program can be used in two modes.

The first is 'view mode' where the model can be called and run as a simple simulation for as long as possible. It may be interrupted to alter the temperature regime or population levels of pest or parasitoid (for example to simulate further releases of parasitoid or mortalities due to spray applications). In practice we find that the model becomes unstable after several months and one or other of the species dies out.

The other is 'control mode' used by the glasshouse control system. The model is run for a short time and an index of the interaction is computed. Within the limits of the energy budget provided we can see whether our cycled temperatures are achieving control. If not, then further simulations compute what extra heating would be required to achieve control or the number of extra releases we would need. This technique presents two problems. How do we compute whether control is succeeding? A method which simply looks at relative rates of increase of pest and parasitoid over the day overlooks the potential of young immature stages. However the success of these young stages will vary depending on the parasitoids activity and the relative temperatures they will experience. We have chosen an index derived by weighting the relative importance of each stage of the life cycle depending on its age.

A related problem concerns whether to use a standard population for every run or to make computations based on a real pest population. The latter requires an estimate of the population to be typed into the computer which in turn computes the rise or fall of the pests on a day to day basis. In addition to the extra work involved, of counting populations, there is a danger that if the computer model underestimates the pest population then it may fail to cycle the temperature adequately. We have therefore worked on the standard population principle so that the control system will be striving at all times to achieve the best control possible.

2 Future Work

Such models are of great value to focus attention on those areas of biology which are of significance in the pest/beneficial interaction. We see such a model as useful not only as a laboratory and teaching tool but as an integral part of a glasshouse control system.

Eventually glasshouse control systems will operate on adaptive and predictive principles. The control system will be programmed with the crop type, the required cropping date and constraints such as the maximum supplementary heating to produce a commercially viable crop. Using data bases for that crop the computer will provide automatic control within the set constraints to optimise the environmental conditions at minimal fuel costs. We see our work contributing to this by including pest control in the system where manipulation of the environment to favour biological control could be considered as part of the overall control strategy.

Up to the time of writing we have concentrated on parasitoid biology but we intend to include mealybug predators into our model. The main problem is to quantify the food value of various prey stages over a range of temperatures and the effect on the predators development, dispersal, searching, and egg development. We would also like to extend the model to pest/parasitoid/predator systems other than the mealybug example. We already have some temperature related information for other systems but welcome such data from other workers.

Although not important in our mealybug control, we intend to include hyperparasitism in the model. Hyperparasitism has a significant effect on aphid control when using Aphidius. We have little idea what part temperature has in this relationship but it might well play a major role.

The most difficult problem is concerned with characterising the suitabilty of the plant hosts to both pest and beneficial insect. Simulating plant growth in relation to pest dispersal and the plant/pest interaction also requires much further work. A great deal of data is required for a model such as this and we need to test our findings in a wide range of conditions. We would welcome cooperation with other workers in comparing our estimates of performance with their observations and in trying to extend our model to other glasshouse pests.

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POPULATION DYNAMICS OF THE GREENHOUSE WHITEFLY TRIALEURODES VAPORARIORUM ON DIFFERENT GERBERA VARIETIES

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Summary

The use of biological control systems in protected crops in the Netherlands is restricted to vegetables. The obtained succes has stimulated the research to possibilities of introducing biocontrol into other crops like ornamentals. Especially in gerbera a low pest population can be tolerated without exceeding the level of economic damage.

This study concerns the population dynamics of the greenhouse whitefly *Trialeurodes vaporariorum* on *Gerbera jamessonii*. Compared with literature data about population dynamics of the parasitic wasp *Encarsia formosa* the results were favourable for stimulating future research.

Introduction

The introduction of biological pest management in Dutch protected vegetable crops is very succesful (van Lenteren *et al.*,1980; Vet *et al.*,1980).

The important role of the host-plant on the interaction between pest and natural enemy was indicated (van Boxtel *et al.*,1978; van Lenteren *et al.*, 1980; van de Merendonk *et al.*,1978; van Sas *et al.*,1978; Woets *et al.*,1976).

Because of the succes in protected vegetable crops and the advantages of biological control above the authentic chemical way, interest increased in the possibilities of introducing biological control in protected ornamental crops. Especially in gerbera, where a low pest population can be tolerated, a well developed biological control scheme might be as succesful as chemical control (van Lenteren *et al.*,1980).

In gerbera the greenhouse whitefly *Trialeurodes vaporariorum* Westwood is a very important pest besides *e.g.* leafminers, red spider mite and thrips. Of all these species natural enemies or very selective pesticides are known.

Control of whitefly in tomato with the chalcid wasp *Encarsia formosa* Gahan is very succesful. To test the biological control possibilities of the greenhouse whitefly with *E. formosa* on a "new" host-plant species, detailed information about aspects of plant-phytophagous and plant-beneficial insect relation is necessary. In our first experiments factors influencing population dynamics of the whitefly on gerbera were estimated and compared with data obtained on tomato.

Materials and methods

Four economic important gerbera varieties were selected: Clementine, Terra - Esperance, Appelbloesem and Terra-Fame; as comparison the tomato, cv. Moneymaker, was used. The whiteflies tested on gerbera were sampled on gerbera, those used on tomato originated from the stock on tomato, used in earlier experiments (van Boxtel *et al.*,1978; Christochowitz *et al.*,1981; van de Merendonk *et al.*,1978; van Sas *et al.*,1978). The experiments were conducted in rearing cabinets under three different temperature regimes: 15, 20 and 25 ± 0.5 °C, rH 70-75 %, L16:D8.

Development time and mortality

During 6 hours whitefly females were allowed to oviposit on the subapical leaf of each host-plant. This leaf is under natural circumstances preferred for oviposition. The eggs were counted and the plants were transferred into the rearing cabinets. The time from egg-laying to emergence was estimated and the number of emerged whiteflies. Mortality was expressed as the difference between the number of eggs laid and number of whiteflies emerged.

Oviposition frequency and adult mortality

On each host-plant species 25 females were tested. Five females were put together into a clip-on leaf cage, Ø 2 cm, within 18 hours after emergence and attached to the underside of the subapical leaf. After 48 hours the cage was transferred to another part of this leaf. The plants were renewed every 2 x 48 hours. The number of eggs laid every 48 hours and the females died in this period were counted.

Roulation experiment

Twenty females, 5 in each cage, of the same age as in the second experiment were allowed to oviposit on one of the gerbera varieties. After 48 hours they were transferred to another variety. The oviposition rate and mortality was estimated.

Results

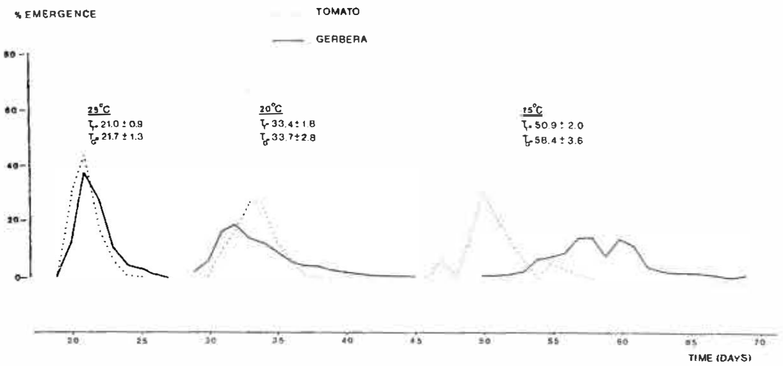
Development time and mortality

The results, presented in table 1 and figure 1, indicate that on tomato the development time of whitefly is significantly shorter than on gerbera (except 20 °C, tomato-Fame; a=0.05). The differences are up to 10 days at 15 °C. Besides, development time on gerbera is less uniform than on tomato. This means, that during a longer period susceptible stages for parasitization by *E. formosa* will be present on gerbera.

Table 1: Mean development time (days) and mortality (%)

	15 C			20 °C			25 °C		
		No	Mort		No	Mort		No	Mort
CLEMENTINE	60.47±3.95	107	10.1	33.99±3.01	413	16.1	21.55±1.28	122	9.6
TERRA ESPERANCE	56.57±3.73	149	5.7	34.77±2.86	235	15.2	21.42±1.10	59	13.2
APPELBLOESEM	58.30±2.96	590	3.3	32.35±1.85	244	10.0	21.76±1.20	110	5.2
TERRA FAME	59.55±3.49	197	7.1	33.47±2.82	274	13.4	21.99±1.55	82	15.5
GERBERA TOTAL	58.40±3.57	1043	5.1	33.68±2.84	1166	14.2	21.69±1.31	373	10.3
TOMATO	50.88±2.04	100	2.9	33.39±1.38	111	1.8	21.01±0.92	115	6.5

Figure 1: Development time of whitefly at three different temperatures



Preimaginal mortality on tomato is in general lower than on the different gerbera varieties. The highest mortality occurs on gerbera at 20 °C, while on tomato the maximum value is reached at 25 °C. Burnett (1949) also found a higher mortality at higher temperatures on tomato. According to his theory it was due to the problem keeping the plants healthy at higher temperatures. Van Sas et al.(1978) found a mortality rate of 60 %. She concluded, that gerbera was a poor host-plant for the greenhouse whitefly because of this high mortality. The experiment was however conducted with whitefly strain tomato. This difference in mortality can be caused in this experiment by the use of a whitefly strain adapted or specialized to gerbera, or to a difference in quality of the used plants.

Oviposition frequency and adult mortality

Oviposition

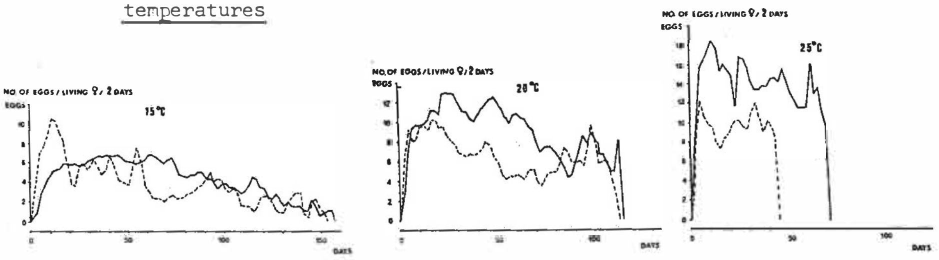
The total fecundity is presented in table 2. Under influence of different temperature regimes there is a considerable variation in the number of oviposition days and the number of eggs laid per female per 48 hours.

Table 2: Fecundity

TEMP(°C)	TOMATO	CLEMEN	ESPERA	APPELB	FAME	GERB MEAN	ROULATION
15	166.2	143.0	168.0	163.6	142.3	154.2	
20	210.7	234.3	274.2	195.1	249.1	238.2	235.1
25	107.0	158.2	289.2	174.1	206.6	207.0	

In figure 2 the results on the four different gerbera cv.'s were put together to indicate the difference between gerbera and tomato. All the graphs show the same trend; a strong increase up to a maximum, followed by a decrease to a certain level and a fluctuation around this level for almost the rest of the oviposition period. Similair trends were found by Van Boxtel et al.(1978) and Van Sas et al.(1978).

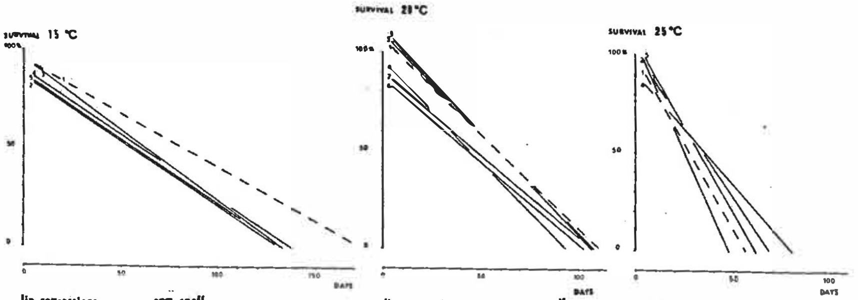
Figure 2: Egg production on gerbera (——) and tomato (---) at three different temperatures



Mortality

The lineair regression of whitefly mortality on different host-plants under three temperature regimes was calculated and presented in figure 3.

Figure 3: Survival rate at three different temperatures. 1=tomato, 2=clementine 3=esperance, 4=appelbloesem, 5=fame, 6=roulation experiment



lin. regressions	corr. coeff.
1 y = 94.855 − 0.545X	0.94
2 y = 86.151 − 0.654X	0.96
3 y = 95.180 − 0.723X	0.95
4 y = 89.335 − 0.650X	0.99
5 y = 87.210 − 0.659X	0.98

lin. regressions	corr. coeff.
1 y = 106.889 − 0.963X	0.99
2 y = 90.455 − 0.848X	0.98
3 y = 110.325 − 1.027X	0.97
4 y = 95.454 − 1.024X	0.98
5 y = 111.764 − 1.050X	0.97
6 y = 87.204 − 0.847X	0.95

lin. regressions	corr. coeff.
1 y = 98.622 − 1.757X	0.98
2 y = 106.768 − 2.271X	0.98
3 y = 101.204 − 1.481X	0.99
4 y = 90.803 − 1.138X	0.98
5 y = 107.070 − 1.774X	0.99

The results indicate an increase of mortality rate with increasing temperature. From these results it is not possible to detect a general difference in host-plant quality between the gerbera varieties at the temperature regimes used in this experiment.

The survival rate of whitefly on tomato at 15 °C is higher than on all of the gerbera varieties. But with increasing temperature the survival potency on tomato become lower as compared to gerbera. At 25 °C tomato has a higher mortality rate than the mean of the survival rate of whitefly on the four gerbera varieties.

Roulation experiment

If four gerbera varieties with different host-plant qualities are exposed to whitefly attack, a roulation of these four may cause a change in behaviour of the whitefly as compared with experiments in which one host-plant variety was offered continuesly. The results, presented in table 2 and figure 3, do not indicate a very strong influence of this roulation, they are more or less intermediates of the results, obtained on the different cultivars offered continuesly.

Intrinsic rate of increase

To summarize the different aspects of factors influencing population dynamics of the different whitefly strains on different host-plants, the intrinsic rate of increase (r) was calculated under the different temperature regimes according to the calculation method described by Birch (1948). These values are presented in table 3.

Table 3: Intrinsic rate of increase of *T. vaporariorum* at different temperatures on different host-plants

TEMP (°C)	TOMATO	CLEMEN	ESPERA	APPELB	FAME	GERB TOT	ROULATION
15	0.0594	0.0455	0.0519	0.0463	0.0451	0.0472	
20	0.0891	0.0801	0.0840	0.0834	0.0871	0.0837	0.0864
25	0.1212	0.1279	0.1381	0.1284	0.1262	0.1302	

Discussion and conclusion

The possibilities for a succesful introduction of biological whitefly control in gerbera are supported by the results of the experiments on the relation between plant and phytophagous insect. When the r-values found in this experiment are compared with the post 1979 values for intrinsic rate of increase of *E. formosa* (van Lenteren *et al.*,1983), the r-values for *E. formosa* are higher at all temperatures tested. However, succes of control differs on various host-plants. A combination of factors apparently is responsible for the ultimate result.

E. formosa shows a preference for oviposition in the instar stages III and IV and in the prepupa. These stages are present after about 55-60 % of the total development period on the host-plant species eggplant, cucumber, tomato and sweet pepper (Woets *et al.*,1976) and also on tomato at different temperatures (Christochowitz *et al.*,1981). Data on the duration of the different stages on gerbera at different temperatures will demonstrate if this ratio between the stages is valuable for gerbera too. This information is necessary for optimalisizing the planning and timing of the *E. formosa* releases.

The influence of the host-plant species on the effectiviness of *E. formosa* was demonstrated by Hulspas *et al.*(1978). They found a correlation between walking-speed of the wasp and parasitization efficiency. The walking-speed was influenced by the structure of the leaf surface, in which the venation and the hair density played a very important role. Because of these leaf properties biocontrol of whitefly failed on cucumber.

Future experiments will concern the following subjects:

- influence of other aspects on the pest-beneficial insect relation like the above mentioned walking-speed of *E. formosa*
- the effect of different gerbera varieties on this relation
- development of an IPM system for gerbera.

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THE DEVELOPMENT OF GREENHOUSE BIOLOGICAL CONTROL IN WESTERN CANADIAN VEGETABLE GREENHOUSES AND PLANTSCAPES

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Summary

Development and application of IPM programs for control of greenhouse whitefly and two-spotted spider mite in western Canadian vegetable greenhouses is outlined. Research on biological control of western flower thrips and aphids is described, as is IPM for use in interior plantscapes.

Development of biological control

In response to development of pesticide resistant whiteflies, *Trialeurodes vaporariorum*, and two-spotted spider mite, *Tetranychus urticae*, in the early 1970's, mass rearing and release experiments with *Encarsia formosa* and *Phytoseiulus persimilis* were initiated at Agriculture Canada's Saanichton Research and Plant Quarantine Station (SRPQS) in British Columbia.

A co-operative program to supply *P. persimilis* and *E. formosa* to commercial growers was established in 1978 by Agriculture Canada and the British Columbia Ministry of Agriculture (BCMA). *P. persimilis* was released onto cucumber plants at the first sign of two-spotted mite damage at an overall rate of 1 predator per plant plus 5 predators for each infested leaf. *E. formosa* was reared by methods similar to those developed at GCRI (Anon. 1975) and released at a rate of 25-50 parasites on every fifth plant.

The program was expanded in 1979 and *P. persimilis* and *E. formosa* were distributed free to 40 commercial greenhouses to introduce growers to biological control. Growers were provided with 10X hand lenses which contributed to the success of the program as growers learned to identify life stages of pests and manage populations of biological control agents. Close contact between growers and extension personnel ensured that the program was successful. Of the 40 growers, 66% indicated that they were willing to pay for biological controls during the following season.

In 1980, with support from commercial growers and the federal and provincial governments, a private company, Applied Bio-Nomics Ltd., began producing and marketing *E. formosa* and *P. persimilis* in British Columbia. Production costs were subsidized at a decreasing rate as sales increased over five years. By 1985 revenue from sales paid all production costs.

By 1980 a total of 50 commercial greenhouse growers in B.C., or 70% of cucumber and 20% of tomato growers by area used biocontrols. Growers in the neighboring province of Alberta became involved the following year. An illustrated handbook (Costello & Elliott 1981), describing the use of *E. formosa* and *P. persimilis* and listing compatible pesticides, aided growers in applying biological control.

In 1981 *E. formosa* and *P. persimilis* were supplied to 105 commercial growers. A survey of these growers indicated that the use of biological control agents had reduced the time spent applying pesticides for whitefly control (60% of reporting growers) and spider mite control (84% of reporting growers). In addition, 23% reported increased crop yields, 38% reported reduced pest control costs and 95% stated that they would continue to use bio-control the following year.

It has been estimated that the use of biological controls in B.C. greenhouses costs 10-20% less than chemical controls.

Current IPM programs

P. persimilis (organophosphate resistant strain originally from the Netherlands) is reared on *T. urticae* infested bush bean, and distributed on leaf pieces (Costello et al. 1984). The most consistant control is obtained when predators are introduced at the first sign of spider mites at a rate of 1 predator per plant. Further introductions of 4,000 to 11,000 predators per hectare are repeated weekly or bi-weekly in affected areas until predators are present on every infested leaf. Fenbutatin oxide is used as an integrated miticide (Anon. 1985).

Control of greenhouse whitefly on tomato and cucumber using *E. formosa* has become more reliable and economical with the use of yellow sticky traps for early detection of whitefly (Quiring 1986; Gillespie & Quiring in press) and weekly releases of small numbers of parasites. *E. formosa* parasitized whitefly scales are glued to cards and are applied at a rate of 1 parasite per 2 cucumber plants and 1 parasite per 4 tomato plants, repeated weekly for 9 weeks or until 80% of all whitefly scales are parasitized. Insecticidal soap can be integrated with *E. formosa* (Putritch et al. 1982) at a reduced concentration (Anon. 1985).

Thrips (*Thrips* sp.) and fungus gnats (*Bradysia* sp. and *Corynoptera* sp.) are controlled by application of diazinon to the floor. Updated information and lists of integrated pesticides are published annually in production guides from BCMA.

The key to the success of biological control programs in western Canada appears to have been the very high level of collaboration on research and development between growers, provincial and federal governments and private industry.

IPM in development

From 1983 to 1985 pesticide resistant western flower thrips, *Frankliniella occidentalis*, caused progressively more serious damage to greenhouse cucumbers in B.C. An early detection and monitoring program was established by greenhouse growers and BCMA. Yellow sticky traps (1 per 50 plants) detected thrips at very low densities, 1 to 2 months before damage appeared on the leaves.

Amblyseius cucumeris, used to control *Thrips tabaci* on pepper in the Netherlands (Ramakers & van Lieburg 1982) was tested at SRPQS in 1985. Trials on cucumber against *F. occidentalis* and *T. tabaci* were successful. In commercial release trials in 1986, thrips were controlled when predators were released at 200,000 per ha per week over a 25 week period on cucumber plants.

Aspects of the biology and life history of *A. cucumeris* are being studied, as is the genetic selection of *A. cucumeris* for pesticide resistance. *Orius tristicolor* and a *Hypoaspis* sp. are being investigated as potential additional biocontrols.

Since 1980, research on the predatory midge, *Aphidoletes aphidimyza*, to control aphids has concentrated on preventing diapause and on testing introduction rates. Nondiapause lines of *A. aphidimyza* have been genetically selected (Gilkeson & Hill 1986b) and it has been shown that diapause can be prevented by using extremely low intensity light at night (Gilkeson & Hill

1986a). Cage studies under winter greenhouse conditions demonstrated the usefulness of *A. aphidimyza* when diapause is averted (Gilkeson & Hill in press). Research on release rates in commercial greenhouses is currently in progress, as are studies on cold-storage of both diapausing and nondiapausing larvae.

Experiments at SRPQS between 1984 and 1986 on the use of *Verticillium lecanii* for the biological control of whitefly on greenhouse vegetables indicated that the fungus was unsuitable due to the long periods of high humidity required for control, short storage life, and high cost of production and registration.

IPM in interior plantscapes

Between 1979 and 1982 an integrated biological pest control program was developed at two large conservatories, the Muttart Conservatory, Edmonton, Alberta, and the Crystal Gardens, Victoria, B.C. (Steiner & Elliott 1983, Steiner 1986). Biological control has since been used extensively in interior plantscapes in western Canada.

Two-spotted spider mite is controlled by introductions of *P. persimilis* and *Typhlodromus occidentalis* integrated with applications of fenbutatin oxide. Citrus red mite, *Panonychus citri*, is controlled with *T. occidentalis* and *Amblyseius californicus*. Greenhouse whitefly is controlled with *E. formosa* integrated with insecticidal soap.

Citrus mealybug, *Planococcus citri*, is controlled with both *Cryptolaemus montrouzieri* and *Leptomastix dactylopii* integrated with kinoprene and insecticidal soap. The soft scales, *Saissetia oleae*, *S. coffeae*, *Coccus hesperidum*, *C. longulus* and *Parasaissetia nigra* and armoured scales such as *Aonidiella aurantii* and *Aspidiotus nerii* are controlled with *Metaphycus helvolus* and *Chilocorus nigritus* integrated with kinoprene and insecticidal soap. Aphids are controlled with *A. aphidimyza* and *Aphidius matricariae* integrated with insecticidal soap or pirimicarb.

Suggestions for future research

The public attitude toward the use of non-toxic pest management is very favorable. This should be used to promote increased funding of biological control research projects. Lists of candidate biocontrols should be made for all major plant pests and research begun to determine those most suitable for mass production and application. High production costs of most biological contols limit their application to certain high value crops. Cost benefit analysis should be applied to other crops particularly if yield increases can be documented with biological control use. Research is needed in developing more efficient production systems for biological controls, utilizing artificial diets or substitute hosts. Long term cold-storage or utilization of diapause or supplementary diets to increase the live storage time is needed. Inert carriers or mechanized dispensers for live biologicals would facilitiate application. Identification and testing of more effective geographic races as well as artificial selection for desirable traits should be pursued. Mechanisms for inventory and exchange of these lines is desirable.

Table 1. 1986 Greenhouse Biological Control Application in Western Canada

Crop (ha)	Pests	Applied in Practice (ha)	Experimental Phase (ha)
Tomato (29)	*Trialeurodes vaporariorum*	*Encarsia formosa* (21 ha)	
Cucumber (30)	*Trialeurodes vaporariorum*	*Encarsia formosa* (22 ha)	
	Tetranychus urticae	*Phytoseiulus persimilis* (24 ha)	
	Frankliniella occidentalis		*Amblyseius cucumeris* (4 ha)

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CONTROL OF GREENHOUSE WHITEFLY, TRIALEURODES VAPORARIORUM, BY THE FUNGUS ASCHERSONIA ALEYRODIS

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Summary

Biological control of greenhouse whitefly by introduction of the parasitoid Encarsia formosa is not successful under all circumstances. To be able to use biological control an additional selective pest-suppressing agent is needed in some situations. Aschersonia aleyrodis is an entomopathogenic fungus, selective on Aleyrodidae and application of this fungus may fit in the integrated-pest-management schedule in glasshouses. Epizootics of A. aleyrodis will not develop under glasshouse conditions, but the fungal spores (infective units) can be applied in the same way as an insecticide. Different aspects of research are discussed. From the experimental results it can be concluded that A. aleyrodis has the potential to be successful against greenhouse whitefly. Future research has to be focussed on mass production, formulation and spraying techniques for development of a marketable product.

Introduction

The parasitoid Encarsia formosa is effective against the greenhouse whitefly, Trialeurodes vaporariorum, on tomatoes (Ravensberg et al., 1983), but on cucumber the excessive hairiness of the leaves impairs its efficacy (Hulspas-Jordaan & Van Lenteren, 1978). Also, cucumber is a better host plant for development of whitefly than tomato. The need for frequent introductions and for careful supervision of the parasitoid's population development makes the use of E. formosa in cucumber economically unattractive. There is, therefore, a need for an additional biological control method, which would fit in the integrated-pest-management schedule for cucumbers.

In preliminary glasshouse experiments Ramakers & Samson (1984) showed that Aschersonia aleyrodis is a promising natural enemy against greenhouse whitefly. The fungus has been reported from several subtropical and tropical areas. It infects Dialeurodes citrifolii and Aleurodes citri in Florida (Berger, 1921, Fawcett, 1944). Results from applying different Aschersonia species to control several whitefly species, either in glasshouses or in citrus orchards, have been reported from Japan, China and Eastern Europe (Uchida, 1970, Fang Qi-Xia et al., 1983, Primak & Chizhik, 1975).

State of affairs

An epizootic of A. aleyrodis - an increasing percentage of pest insects succumbs by infection through time - does not develop in a glasshouse situation. The spores of *A. aleyrodis* are produced in slimy masses in pycnidia and dispersal of these 'infective units' takes place by means of water. Rain or overhead irrigation is not present in a cucumber growing environment. Condensation of water on a leaf surface may enable spores to move from a sporulating insect to a susceptible insect on the same leaf, but this will not be sufficient to create an epizootic. Besides, the whitefly population shows, especially early in the season, a distinctive age structure. Whitefly females prefer to lay eggs on young top leaves of the plant. Therefore, eggs can be found on the young leaves and older instars are found successively downward in the canopy. It is not possible to get spores from the infected instars on the underside of the lower leaves to the healthy instars on the underside of the younger leaves without any human intervention. Except the dispersal of spores by water insects can transport spores from one site to another. Nevertheless, this will hardly contribute to a high percentage of infected whiteflies within a relatively short time period. Thus, after a single introduction of spores of *A. aleyrodis* in a cucumber crop, only a direct effect is present and an increase of infection through time will not take place. Therefore, *A. aleyrodis* spores are applied as a microbial insecticide.

Spores of entomopathogenic fungi can infect insects by penetration of the gut wall after ingestion or directly by penetration of the insect cuticle. Whitefly is a phloem feeding insect and spores can only cause infection by penetration of the host's cuticle.

When applying spores of *A. aleyrodis* as a microbial insecticide, in a glasshouse situation, the following aspects are of importance:

(i) fungal characteristics: germination, virulency, sporulation, viability, in relation to mass production on artificial media and activity in the field.

(ii) host characteristics: population dynamics, density, developmental rate, differential susceptibility.

(iii) environmental characteristics: water, relative humidity, temperature, canopy, light, soil, wind.

(iv) product characteristics: shelf life, standardization, formulation, spraying techniques.

(v) side effects: a. effect on beneficial insects
b. use of fungicides/insecticides
c. toxicological aspects

(i) *A. aleyrodis* is growing on (semi) artificial media. Sporulation only occurs on solid media. This may complicate the scaling-up of a mass rearing system. Research may be directed in two ways:

a. up-scaling mass production on solid media
b. investigating the possibilities of producing spores in liquid fermentation.

The survival of the spores on the abaxial leaf surface may play a role causing mortality of whitefly larvae some time after application of the fungus. Spores remain viable and infective on the underside of cucumber leaves for 22 days at 20°C and 70% RH (Fransen, 1986).

(ii) The treatment of greenhouse whitefly belonging to different developmental stages results in differences in infection. Eggs are not infected by *A. aleyrodis* spores but the spores stay viable on the leaf surface and newly hatched larvae become infected. The average percentage infection of whitefly larvae treated as one-day-old eggs, as eight-day-old eggs and treated as a mixture of first and some second instar larvae amounted to 94%, 93% and 90%, respectively. The average percentages infection of treated third and fourth instar larvae and prepupae were 76%, 28% and 12%, respectively. These infection percentages were observed after application of 2 ml of spore suspension ($4x10^6$ sp/ml) by means of a

Potter spray tower. (Fransen, in prep.). The LD_{50} is 1 to $2x10^{6}$ spores when applied to first, second or third instar larvae and $5x10^{7}$ spores when applied to fourth instar larvae. Whitefly adults do not become infected by A. aleyrodis spores under the tested circumstances. Several applications of A. aleyrodis have to be carried out to successfully suppress a whitefly population. The timing of the applications in relation the population structure of whitefly will also play an important role.

(iii) Infection of whitefly by A. aleyrodis is influenced by external conditions like relative humidity and temperature. Application as a microbial insecticide restricts this dependence to the time period between application and penetration of the host insect. The infection of whitefly takes place under the climatological conditions present in a glasshouse situation.

(iv) Application of A. aleyrodis in laboratory experiments resulted in successful infection of whitefly larvae. Single applications of A. aleyrodis in experimental glasshouses, however, gave variable results. Leaves were observed bearring 90% infected whitefly larvae but leaves were also present bearing only 20% infected whitefly larvae. This was due to the variable coverage of the underside of the cucumber leaves. Repeated applications of A. aleyrodis spores gave good results (Ramakers & Samson, 1984). Nevertheless, product development using appropriate formulation and application techniques will contribute to an optimal use of the spores.

(v) (a). As we intend to use both natural enemies of greenhouse whitefly, E. formosa and A. aleyrodis in a glasshouse situation, the timing and frequency of the application of A. aleyrodis in relation to the introduction of E. formosa become important. For this reason detailed knowledge is needed on the interaction of these two natural enemies.
After application of A. aleyrodis the parasitoid females are able to distinguish healthy from infected hosts when colonization of the host by the fungus has taken place. During the time period after spraying before symptoms of infection appear, larvae may be parasitized, but will succumb of infection by the fungus. When E. formosa is able to discriminate between infected and noninfected hosts, the effect of both natural enemies is complementary. Nevertheless, even during the time interval before symptoms appear E. formosa eggs may escape infection by the fungus as the parasitoid prefers to parasitize fourth larval instars, which are showing a lower susceptibility to fungal infection than the younger larval instars. When parasitization takes place within three days before application of A. aleyrodis these hosts may succumb by infection, but the developing host becomes resistant against to infection with age. The black pupae, which contain a parasitoid larvae are not susceptible to infection by the fungus.
(b) The application of A. aleyrodis has to be integrated into the management system of control measures against other pests and pathogens. Especialy the use of fungicides may inpair the effectivity of A. aleyrodis. Experiments were carried out applying mancozeb, a fungicide detrimental on A. aleyrodis, at different time intervals after application of A. aleyrodis on cucumber plants bearing whitefly larvae. It was shown that applying the fungicide about 6 days after A. aleyrodis application resulted in the same number of infected larvae compared with the number in the control treatment. Using a most detrimental fungicide a safety period of six days will not interfere with the infection process of whitefly by A. aleyrodis spores. There are, nevertheless, other fungicides which have a less devastating effect on spore germination and mycelial growth of A. aleyrodis (pers. comm. Ramakers) which may involve an even shorter safety period or may be applied at the same day as spores of A. aleyrodis.
(c) Aschersonia aleyrodis is a very selective entomopathogenic fungus,

only reported to infect scales belonging to the Aleurodidae. Toxicological tests have to be carried out before registration will be allowed.

Discussion

The following advantages are present when using A. aleyrodis against greenhouse whitefly.

1. The outcome of an application of A. aleyrodis can be evaluated by the grower, as infected whitefly larvae become orange coloured and can clearly be distinguished from healthy whitefly larvae and pupae (transparent or opaque white) and parasitised pupae (black).
2. The application of the spore suspension can be carried out during any time of the day. Successful infection was achieved after spraying A. aleyrodis during midday when the temperature was about 30°-35°C and the relative humidity was 50%.
3. A. aleyrodis is able to infect whitefly larvae also when temperatures are constantly high (30°C). Thus, the fungus shows prospects for use in environments where temperatures can be high.
4. A. aleyrodis being a selective pathogen on whitefly larvae, does not cause any detrimental effects to other natural enemies used in the glasshouse environment.
5. There is some competition for hosts using A. aleyrodis and E. formosa together but E. formosa can survive an application of fungal spores as black parasitized whitefly pupae and adults do not become infected. E. formosa may act complementary to A. aleyrodis by discrimination of healthy and infected hosts.
6. The application of fungicides or insecticides can be integrated with the use of A. aleyrodis. Sometimes, however, a safety period has to be taken into account.

The disadvantage of the application of A. aleyrodis mainly lays in the fact that only whitefly larvae are successfully infected. Therefore, several applications have to be carried out to achieve a reduction of the whitefly population.
At present the optimal timing and frequency of spore applications are investigated by means of simulation modelling.
Future research has to be aimed at:

a) the development and optimization of the mass production of the fungal spores.
b) the development of a formulated and marketable product.
c) the optimization of the application technique for obtention of good coverage of the undersides of the leaves.

In 1986 a study group of the IOBC/WPRS in insect pathogens and insect-parasitic nematodes was established. The main aim will be to provide a grouping of scientists which will stimulate collaborative research to provide practical answers to pest problems in agriculture and horticulture in view of the use of micro-organisms. Cooperation and communication between the different countries in necessary to exploit the possibilities of new methods of microbial pest control, testing these agents in various crops under different environmental conditions and cultural practices.

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APHID CONTROL ON CHRYSANTHEMUM USING FREQUENT, LOW DOSE APPLICATIONS OF *VERTICILLIUM LECANII*

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Introduction

The entomogenous fungus *Verticillium lecanii* has been developed for aphid control on chrysanthemums (Hall & Burges, 1979) and has shown variable levels of control amongst different species of aphids. The manufacturer's recommended application rate is 2.5 kg product/ha in 1000 l of water two weeks after planting. Using this method, control of *Myzus persicae* is generally good but control of *Aphis gossypii* is inadequate, often less than 80% (accumulated ADAS Reports 1980-1985). Under glasshouse conditions, *M. persicae* is more susceptible than *A. gossypii* to infection by *V. lecanii* (Hall, 1985). This may be due to the more sedentary nature of the latter aphid species which may inhibit the spread of an infection.

After application, the spores require a period of high relative humidity for successful germination and infection. The spores germinate on the insect cuticle or on a carbohydrate carrier material included in the formulation. Infection occurs by hyphal penetration through the cuticle and dead insects may be observed as white "fluffy bodies", which adhere firmly to the plant, some 1-2 weeks later. Under favourable conditions of high RH and temperatures between 15-25°C the infection may continue to suppress the pest population (Samson & Rombach, 1985). However, if these conditions are not encountered, control and spread of the infection would be greatly impaired.

In order to improve control of *A. gossypii* on chrysanthemums, *V. lecanii* was applied twice weekly at 1/12 the normal dose. This was aimed at increasing establishment and spread of the infection by giving the fungus a better chance of encountering the right conditions more frequently. The integration of potentially harmful fungicides also appears possible with this method. The work described is a demonstration trial for a grower's meeting and an ADAS trial with ultra low volume (ULV) application methods. The ULV trials were conducted in an effort to reduce the application time and the volume of water, so minimising fungal disease risks.

Methods

For the demonstration trial a glasshouse compartment (83 m^2) was planted on 9 January 1986 with three beds of chrysanthemum, each bed containing 350 plants. The varieties in each bed were; Belair, Hurricane, Light Pink Gin, Roswan and Sulphur Westland. The plants were grown under commercial conditions, i.e. supplementary lighting to provide a 16 h day for two weeks after planting, followed by polythene blackouts for 10 weeks. The plants were evenly infested with *A. gossypii* and *M. persicae* by placing small leaf pieces from stock cultures evenly over the bed. This was done several times during the first three weeks of the trial to establish a population of mixed ages before any treatments began. Bed one was an untreated control and beds two and three were treated with low-dose, twice weekly *V. lecanii*. Bed three also received four applications of four fungicides (fungicide integration).

V. lecanii was applied as a mist (600-800 l/ha) to the tops of the plants of beds two and three by knapsack sprayer, at 0.21 g Vertalec product/l. Bed three also received fortnightly sprays of fungicide mixtures containing iprodione + mancozeb/zineb + triforine along one side and iprodione + propiconazole along the other. These were prepared at the manufacturers' recommended concentration for chrysanthemum and applied at high volume (HV) to just-before-run-off by knapsack sprayer.

Aphid numbers were monitored weekly by random sampling of 50 plants from each bed taking equal numbers from each variety and recording the number of aphids per plant, the number of plants infested, their position within the bed and the variety of chrysanthemum. Temperature and humidity were monitored from within an aspirated screen and at top-of-plant height using thermohygrographs. From mid-February onwards, a data logger (Grant Squirrel SQ2 3U/1L) was used, the probes were positioned alongside the thermohygrographs for direct comparison.

ULV application trials were conducted on a 0.2 ha block of pot chrysanthemums using a Turbair Fox from May-July and a Dynafog Mister II from July-October. Pots of five cuttings each were placed on 2 m wide benches, Turbair applications were made by spraying one bench either side of the operator in two passes of opposite direction on each occasion. Fogs were applied from a central pathway, directing the machine over each bench, until fog rolled back to the operator from the wall of the glasshouse 14 m away. The commercial product Vertalec was applied twice weekly at 0.5 g product in 17 ml water per 1000 cuttings. This was later reduced for the Turbair trial to 0.25 g product applied similarly. In addition to Vertalec, a non-commercial V. lecanii formulation (the standard) with no carrier but five times the concentration of spores was tested through both machines. The standard formulation was used at one fifth the rate of Vertalec.

Healthy and diseased aphids were assessed twice during both trials by randomly sampling 50 pots each time. Sterile Petri dishes containing a layer of Sabouraud dextrose agar (SDA) were used to determine the number of viable spores landing at various distances from each applicator. The dishes were exposed for 10 seconds for the Turbair tests and 30 seconds for the Dynafog tests. Towards the end of the trial a chemical fog dispersant (diethylene glycol) was added to help dissipate the fog droplets and make them more visible to the operator.

Results & Discussion

Aphid numbers initially increased on all beds of the demonstration trial to produce high numbers until V. lecanii began to exert control. Peak numbers of A. gossypii were lower on both treated beds than on the control to which V. lecanii had also spread by the end of the trial (see Figs. 1 and 2). The aphids appeared to have varietal preferences; M. persicae occurred mainly on Belair, Light Pink Gin and Roswan, whereas the highest numbers of A. gossypii were on Hurricane with occasional plants of the other varieties infested. The variety Sulphur Westland which has a smooth shiny leaf surface was least preferred by both species. However, the position of the plants in each bed was similar, so a positional preference within the bed or glasshouse rather than a varietal preference cannot be ruled out.

The first cadavers (dead infected aphids) were observed on 19 February almost four weeks after spraying began. This was slower than normal and possibly due to low temperatures with often low humidities.

The glasshouse used has steam heating pipes around the edge with no facility for heating along the line of a crop or under blackouts. Hence the area under blackout remained cooler (14°C instead of 16°C) than the rest of the house because the thermostatic control was placed above the blackouts. Once this had been rectified (mid-February - after five spray applications) the V. lecanii treatments began to work very well.

The integration of fungicides resulted in comparable control of aphids to the straight V. lecanii treated bed, there being no differences between the various fungicide treatments. However, until the end of the trial, the number

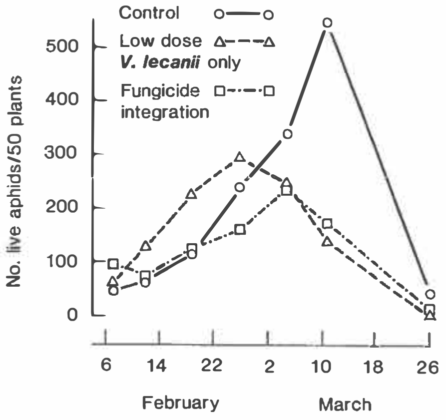

Fig. 1. Live aphid numbers

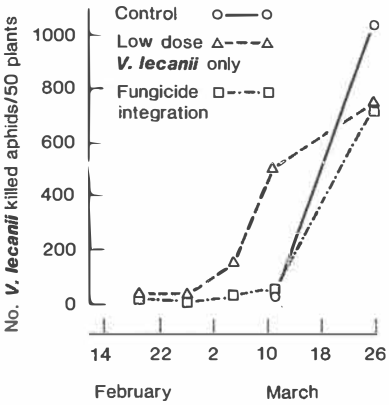

Fig. 2. Diseased aphid numbers

of white bodies was lower on the fungicide-treated bed than on bed two. Thus the chemicals may have had an effect on the *V. lecanii* but because of the repeated application of spores, control by the pathogen could still occur. This is a useful advantage, as the recommendation for integration of fungicides with a single application of spores is to apply the fungicide at least seven days or more *before* spraying *V. lecanii* (Hall, 1985).

In contrast to the demonstration trial, low numbers of both species of aphids were maintained throughout the ULV application tests. Following Turbair applications of 0.5 g Vertalec/1000 cuttings only 10% of the pots were infested with aphids (1-2 aphids/pot) all of these had been killed by *V. lecanii*, the remaining pots were free of aphids. However, this treatment caused a white deposit on the foliage which needed to be masked before marketing by a spray of petroleum oil. The reduced rate of Vertalec (0.25 g/1000 cuttings) also gave good control but, on the variety Delicious 70% were infested with approximately five aphids per pot, of which 94% had been killed by the fungus. There was no visible deposit.

Following the fogging programme few aphids were found, except on the variety Delicious where occasional pots had up to 50 aphids, all of which were diseased. The inclusion of diethylene glycol reduced the effectiveness of the spores; on Delicious only about one third of the aphids were diseased and nicotine sprays became necessary.

An assessment of *V. lecanii* distribution on SDA plates is given in Table 1. Both methods of application appear to have distributed adequate numbers of viable spores over several metres from the operator. A higher number of spores seemed to have been delivered when the standard formulation rather than the commercial Vertalec was used. When diethylene glycol was used in the fogging solution no colonies of *V. lecanii* developed, and so cannot be recommended as a dispersant with *V. lecanii*.

Table 1: Numbers of Verticillium lecanii colonies on agar-dishes placed in chrysanthemums treated with a ULV machine and with a fogger

Method of application	Product	Rate of application (g/1000 plants)	Distance of dish from machine (m)	Number of *V. lecanii* colonies
Turbair	Vertalec	0.5	<2	122
"	Standard product	0.1	<2	198
"	Vertalec	0.25	<2	23
Fog	Vertalec	0.5	2	676
"	"	"	4	428
"	"	"	6	80
"	"	"	8	80
"	"	"	10	56
"	"	"	12	28
"	"	"	14	7
"	Standard product	0.1	1	73
"	" "	"	2	922
"	" "	"	4	836
"	" "	"	6	139
"	" "	"	8	102
"	" "	"	10	70
"	" "	"	12	43

Conclusions

The frequent low dose application method provided good control of both species of aphid and can be integrated with potentially harmful fungicides. The very high numbers of aphids in the demonstration trial were, in part, due to the low temperatures which occurred during the critical early treatment stage which reduced the effectiveness of *V. lecanii*. Also the plants were heavily infested from the start, which would not normally happen. The flexibility of this treatment is evident by the good control achieved under the adverse conditions of this trial.

The ULV application methods tested worked well, giving good control of both aphid species. These methods are advantageous because less time is spent applying the material and little water is used, so reducing disease risks. Using the more concentrated standard formulation would reduce the white deposit on foliage and the possibility of machine blockages.

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Advantages of oligophagous predatory mites for biological control.

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According to present experiences in the GDR injurious mites and insects in greenhouses have to be controlled by several antagonists which show different application parameters (prey spectrum, dispersion, temperature optimum, and relative atmospheric humidity).

The present study deals with predatory mites of the family Phytoseiidae BERLESE. Environmental conditions and prey differ from crop to crop.

15 wide-spread species of this family of predatory mites have been analyzed according to food spectrum and preference (table 1). The most important prey are spider mites (Tetranychidae). Special advantages show so-called oligophagous species of predatory mites, because they also feed on other groups besides spider mites.

Oligophagous predatory mites have two advantages: first, different pests are controlled at the same time, secondly, prey objects for mass rearing can be produced at low costs and low expenditure of work and energy. Mites from storage dumps (Tyroglyphidae) proved to be especially suitable. According to food spectrum of the chosen predatory mites they are eaten by Amblyseius barkeri, A. cucumeris, A. rademacheri, Euseius finlandicus, Phytoseius macropilis, and Typhlodromus pyri (table 1). 6 species have not been checked till now according to feeding on mites from storage dumps and augmentation.

Until now we have especially investigated Amblyseius barkeri. The principle of augmentation and their efficacy for controlling thrips are known from Dutch investigations (RAMAKERS, 1982; RAMAKERS and LIMBURG, 1982). First tasks of the GDR were to find practicable technologies of mass rearing and examine the efficacy of predatory mites as antagonists of the Two-spotted spider mite. Pict. 1 shows the technological scheme of mass rearing for oligophagous predatory mites. Table 2 shows measurements, demands, and capacity of a station, which is useful for farming centres. Breeding dishes for prey and predatory mites are in frames covered foil (pict. 2).

First investigations in laboratory should show with which efficacy the predatory mite feeds on spider mites. 100 adult Tetranychus urticae were put on a bean leaf in a petri-dish (d = 55 mm, h = 30 mm), and 10 adult predatory mites were added. The dish was covered with a disc of filter paper. For adhesion the rim of the dish was covered with lime. The dishes were put into an exsiccator with saturated sodium chloride solution, temperature $\bar{x} = 20\ ^{o}C$. Table 3 shows the results of the petri-dish tests.

Biological control of spider mites according to conditions of industrial farming had been tested in a foil greenhouse for three years. The first experiment was made with 200, the second with 150 cucumber plants. Each plant had approximately 70 leaves. Each leaf was infested by $\bar{x} = 5$ respectively 3 to 4 spider mites. Each plant was sprinkled with 10 tea-spoons full of wheat bran with predatory mites ($\bar{x} = 100$ predatory mites per plant). In the first experiment 40 plants and in the second 25 plants were not treated.

For analyzing the density of spider and predatory mites on 5 leaves at different heights of plants each was periodically investigated. Pict. 3 shows the results of the first experiment, pict. 4 those of the second.

In both years the spider mite density after application of predatory mites declined already after 7 days to 1 to 2 spider mites per leaf, whereas the check-plants showed mass augmentation.

In 1986 a large-scale experiment with cucumbers was made in a plastic greenhouse of 1350 m^2. 3 days after planting 300 to 400 predatory mites were put on the running metre of cucumbers. A second application was done after 3 months at 16. July.

During the whole period of growing (till 10. August) the rate of infestation by spider mites and thrips could be kept below the economic threshold on the main area of the greenhouse. Only at

28. July the plants near the door had to be treated by an acaricide because of a strong decline in relative atmospheric humidity.

Conclusions

Oligophagous predatory mites are advantagous for biological control. Investigations on Amblyseius barkeri showed that predatory mites not only feed on thrips, but also on the movable instars of spider mites and Tyroglyphidae. This provides favourable conditions for a complex biological control. Mass rearing of oligophagous predatory mites can be done at low costs in small cabins. Transport and application within the crop can be simplified. Table 4 shows the so far known parameters of the predatory mite Amblyseius barkeri.

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Table 1 Food-spectrum of predatory mites (Phytoseiidae BERLESE)

prey: predatory mite	larvae + eggs of insects	mites of stored food (Tyroglyphidae)	spider-mites (Tetranychidae)	gall-mites (Eriophyidae)	Tarsonemids (Tarsonemidae)	other food
Amblyseius aberrans (OUDS.)	–	?	+	+	?	mildew
A. aurescens A.-H.	–	?	+	?	+	honeydew
A. barkeri (HUGHES)	+	+	+	–	?	pollen honeydew
A. cucumeris (OUDS.)	+	+	++	–	+	honeydew
A. fallacis (GARMAN)	?	?	++	+	?	?
A. potentillae (GARMAN)	?	?	++	+	?	pollen honeydew
A. rademacheri DOSSE	–	+	++	?	?	–
Anthoseius rhenanus (OUDS.)	?	?	++	+	?	plant juice
Euseius finlandicus (OUDS.)	–	+	+	+	+	pollen mildew honeydew
Metaseiulus longipilus (NESB.)	?	?	+	+	?	
M. occidentalis (NESB.)	+	?	+	++	+	
Phytoseiulus persimilis A.-H.	–	–	++	–	–	–
Phytoseius macropilis (BANKS)	–	++	++	+	–	–
Seiulus tiliarum (OUDS.)	–	–	++	+	+	–
Typhlodromus pyri SCHEUTEN	–	+	+	++	–	pollen mildew plant juice

Table 2

Requirements and efficiency of a mass rearing station for oligophagous predatory mites in farming centres

Room:	2 separate cabins, each 3 x 2 x 2 m^3
Equipment:	2 frames with 6 to 8 levels for placing breeding containers with system of pipes for ventilation
Breeding containers:	a) 120 to 160 dishes for breeding substrat (30 x 25 x 6 cm) b) 120 to 160 dishes, somewhat larger, with water as barrier to migration
Tools:	2 blower engines, 2 washing-bottles
Instruments:	4 polymeter (for relative humidity, temperature)
Need of labour:	4 to 5 man-hours per day
Efficiency:	26 millions predatory mites in 30 days

Table 3

Effectiveness of the oligophagous predatory mite Amblyseius barkeri

Results of 2 tests with 5 x 100 spider mites and 5 x 10 predatory mites in petri-dishes

Average rate of killed spider mites in %

after	1 d	2 d	3 d
with predatory mites, test 1	49,6	86,0	100,0
- " - , test 2	49,2	74,0	99,6
check, without	0,5	2,5	5,5

Table 4

Prey consumption, conditions of development, and costs of mass rearing

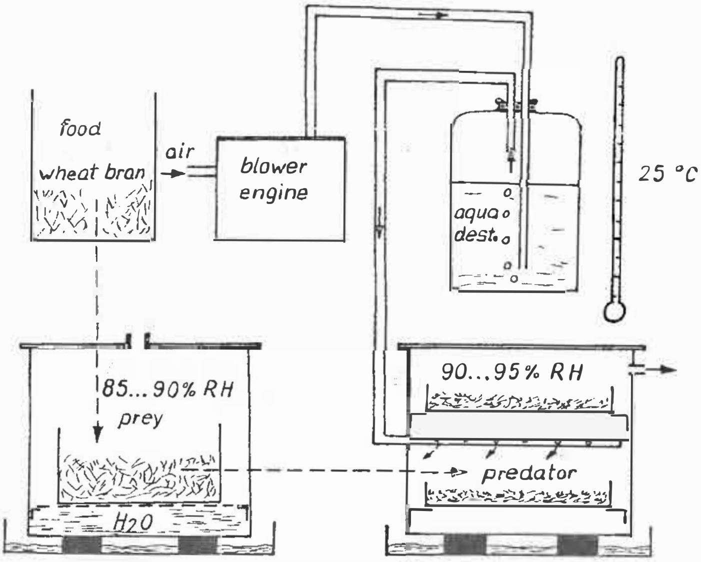
Prey consumption of Amblyseius barkeri per day		
- movable instars of Tetranychus urticae:		4 to 8
- larvae of insects: (thrips)		5 to 8[1]
Temperature:		20 to 25 °C
Relative humidity necessary for development of Amblyseius barkeri		
- for eggs:	85 %	
- for larvae:	90 %	
- for proto-nymphs:	85 %	
Cost of production per 1000 predators:		0,15 M to 0,20 M
Need of energy per 1000 predators:		0,01 kW

---

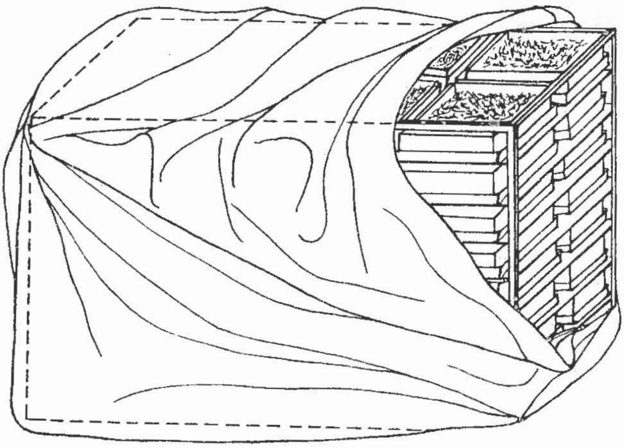
[1] after BEGLJAROV and SUCHALKIN (1983)

Pict. 1

Breeding method of oligophagous predatory mites

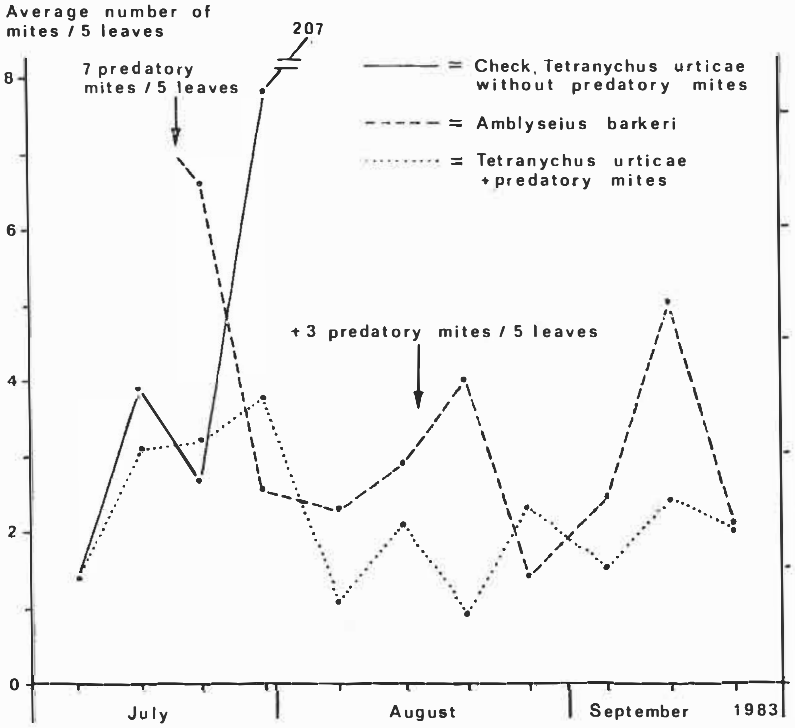


prey: *Tyrophagus putrescentiae* predator: *Amblyseius barkeri*

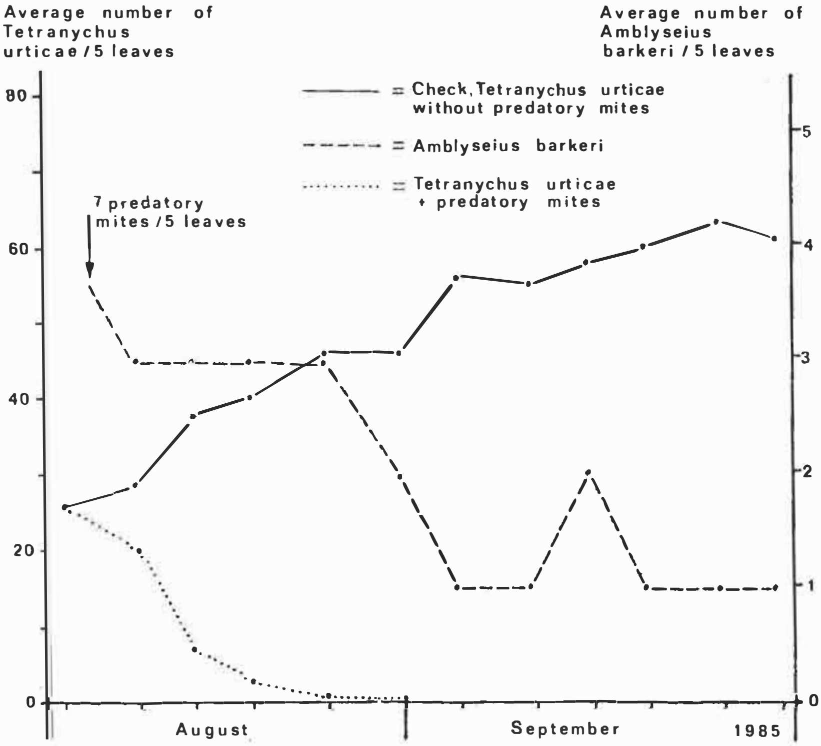


Pict.2 Frame with breeding containers

Pict. 3


Average number of
mites / 5 leaves
207
7 predatory
mites / 5 leaves
——— = Check, Tetranychus urticae
without predatory mites
- - - - = Amblyseius barkeri
········ = Tetranychus urticae
+ predatory mites
+ 3 predatory mites / 5 leaves
8
6
4
2
0
July
August
September
1983

Pict. 4


Average number of
Tetranychus
urticae / 5 leaves
Average number of
Amblyseius
barkeri / 5 leaves
——— = Check, Tetranychus urticae
without predatory mites
- - - - = Amblyseius barkeri
········ = Tetranychus urticae
+ predatory mites
7 predatory
mites / 5 leaves
80
60
40
20
0
5
4
3
2
1
0
August
September
1985

LIRIOMYZA TRIFOLII (BURGESS) INFESTATIONS AND YIELDS OF GREENHOUSE TOMATO

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Summary

Tomato plants at the six-leaf stage, pre-bloom and first-bloom stages were exposed to adult flies for 3-4 days in an attempt to affect the size and number of fruits developing in the first inflorescence. Although the infestation level on exposed plants was not consistently high, control plants became infested to a much lower degree by naturally occurring flies. Differences in infestation levels were highly significant in all experiments ($p<0.001$). However, yields of marketable fruits, either size or number, in the first cluster were not significantly reduced. Compensation by the plant for tissue destroyed in the course of the insects' development at the time of the infestation could have been responsible for this lack of yield reduction.

1.1 Introduction

As part of an attempt to develop practical IPM and/or BC programs for Ohio greenhouse vegetable growers, several studies have been conducted to evaluate the use of parasites for leafminer (*Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae)) control on tomato (e.g. Fogg, 1981, Lindquist and Casey, 1983). Results, using *Opius dimidiatus* (Ashmead) (Hymenoptera: Braconidae) and *Diglyphus intermedius* (Girault) (Hymenoptera: Eulophidae), generally indicated that there was excellent potential for a leafminer BC program. However, a possible drawback to the use of parasites is that leafminers sometimes reach quite high population levels before the parasites obtain control. This could affect early fruit production.

Earliness in supply of marketable tomato fruits is one of the most important factors for Ohio greenhouse growers to compete successfully with producers from other areas. Growers must ensure that the economic threshold for pests likely to affect the plants' growth and development for the first harvest is not exceeded. Leafminers can be one of the most serious pests of the tomato plant at any stage and can be especially devastating if the infestation starts early in the season. A heavy infestation as early as the cotyledon stage can kill the plants outright (unpublished data).

However, very serious damage to greenhouse tomatoes so early in the season is rare and occurs mostly when seedlings for a subsequent crop are produced in the same greenhouse as a heavily infested mature crop. If the initial leafminer infestation is not very serious, the effect of the insect on tomato plants becomes less obvious, and may or may not affect yields or fruit quality.

Investigations into the relationship between leafminer infestation levels and yield reductions have lead to different conclusions. The time of infestation as well as the change in severity of the infestation in the course of the season can determine whether yield will be reduced or not. A serious problem in the research into this relationship is obtaining predetermined infestation levels on the test plants. Simulating leafminer damage by manual defoliation has been tried on numerous occasions (Keularts et al., 1985). However, comparing results of these experiments with natural defoliation following leafminer infestation is not easy. The abruptness of manual leaf removal deprives plants of nutrient reserves immediately and it may take a while before the plants can make up for this loss. In addition, the way in which plants recover may not be identical between the two damage patterns.

Leafminers seem to prefer older, fairly mature leaves for oviposition and in the 3 to 6 days before eclosion young leaves can increase considerably in size and, therefore, photosynthesis ability. During the gradual removal of mesophyll from the leaves by the larvae compensatory tissue may be formed elsewhere within the canopy. Fruit size and number may the be completely unaffected.

In an attempt to determine the effect of leafminers within the tomato canopy on yield, tomato plants at different stages of development were exposed to large populations of adults. Subsequent fruit yields and quality were then measured on the first cluster.

1.2 Description

Because of space limitation (greenhouse size of 12 x 12 m allowed for a maximum of 104 plants) each infestation experiment consisted of only two treatments: infested and control plants. Tomato plants were exposed at the six-leaf (vegetative) stage, at pre-bloom (2 experiments) and at first-bloom. To achieve controlled infestation of the plants at the different times they were exposed to large numbers of leafminer flies in cages for 3 to 4 days. The plants were growing in pots at the time they were placed in the cages. All plants exposed at the six-leaf stage were subsequently transplanted into ground beds in the greenhouse. The development of the second generation of the insect was prevented by applying cyromazine to all plants used in the experiments. All other plants were kept in the pots while placed on the ground in the greenhouse. Eventually the root system of these plants passed through the drainage openings of the pots into the soil. Except for the placement in the fly cages, control plants were treated identically to the infested plants. Nevertheless, most control plants became slightly infested because of the natural presence of flies in the greenhouses. The number of mines on the deliberately infested plants was between 2 and 4 times the number on the control plants. All cultural practices carried out in commercial greenhouses were applied.

1.3 Results

Despite a very significantly higher infestation level ($P<0.001$) in the infested plants as compared to the control plants, yield was not reduced in any of the four experiments. Neither marketable yield nor total yield was reduced as a result of the leafminer infestation. Only among the unmarketable fruits were some differences significant. However, these differences were not consistent.

The results of the four experiments are summarized in Table 1.

STAGE OF INFESTATION	TREATMENT	Number of mines[a]	FRUIT WEIGHT (g) Sound fruit	Culled fruit	Total	FRUIT NUMBER Sound fruit	Culled fruit	Total
six-leaf	infested	17.1	350.1	82.0	432.1	2.80	0.60	3.40
	control	4.2	259.9	102.8	362.7	2.45	1.05	3.50
pre-bloom (i)	infested	23.9	629.1	196.8	825.9	3.13	1.10	4.23
	control	12.9	637.6	227.3	864.9	3.23	1.23	4.46
pre-bloom (ii)	infested	23.8	539.1	192.5	731.6	4.47	0.88	5.33
	control	7.1	544.3	96.1	640.4	4.68	0.36*	5.04
first-bloom	infested	13.8	400.0	46.1	446.1	4.34	0.41	4.75
	control	2.9	384.1	80.3**	464.4	4.09	0.72*	4.81

[a] Average number of completed mines per infested leaf (infestation levels significantly different at $P<0.001$).

[*] Values of control and infested plants significantly different at $P<0.05$.

[**] Values of control and infested plants significantly different at $P<0.01$.

2.1 Future Research

Partitioning of the effect of leafminer damage into delay or alterations in the early development of the first inflorescence and fruit fill should be determined. Flower and fruit abortion may be one of the consequences of removal of part of the nutrient sources for the inflorescences.

3.1 Discussion

The method in which leafminers interfere with the development of fruit is not fully known yet. A relatively small reduction in the supply of nutrients to the fruit may not affect its development because of adequate reserves from other sources or compensation by the plants by producing extra foliage. The duration of the leafminer infestation, especially when its population is not controlled, could reduce the nutrient supply faster than the plant would be able to compensate for, resulting in smaller fruit.

The development of each inflorescence seems to be determined very early which means that very young leaves, normally not damaged by leafminer adults, contribute most if not all of the nutrients to this structure. Leafminer infestation would, therefore, not affect the potential of each inflorescence but only its subsequent development in terms of increased flower and fruit abortion and early maturation.

Whether there is a linear relationship between the reduction in photosynthetic activity of the tomato leaf and the area destroyed by the leafminer larvae also is unclear. Ten first instar larvae killed by parasites may have the same effect as one third instar larva ready to pupate.

Although questions certainly remain, based on these results and observations on parasite effectiveness, there appears to be excellent potential for a BC approach to *L. trifolii* management on greenhouse tomato.

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WORLD SITUATION OF BIOLOGICAL CONTROL IN GREENHOUSES AND FACTORS LIMITING USE OF BIOLOGICAL CONTROL

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1.Introduction

The world area covered with greenhouses is about 100000 to 150000. Biological control of pests in this cropping system started in 1926 when Speyer introduced the parasite Encarsia formosa against the greenhouse whitefly Trialeurodes vaporariorum. Before the use of synthetic pesticides this parasite was applied in several countries in Europe, in Canada, Australia and New Zealand. When broad-spectrum pesticides appeared, the use of biological control was terminated. After the first cases of arthropod resistance during the 1950's new interest for biological control developed. Around 1960 an efficient predator, Phytoseiulus persimilis, of spider mite, Tetranychus urticae, was found. Successful application of this predator led to re-introduction of Encarsia formosa. Since this revival, biological control in greenhouses has achieved a firm basis. The number of researchers and countries applying biological control techniques has increased steadily during the last 20 years. Bulletins of our working group - five of these are published since 1970 - and information from a newsletter (Sting, published since 1978) provide information of the developments of the last 13 years.

2.Statistics on the use of natural enemies

I have used information from Bulletins and Sting to make up table 1, which provides data for the different natural enemies per year, and table 2 which contains summarized information from previous working group meetings. I am convinced these lists are incomplete. Therefore, I would be very happy if mistakes and/or additions are mentioned to me. It is rather difficult to collect reliable information. This kind of information is, however, necessary to show policy makers and the general public how realistic IPM in greenhouses is.

Table 1. Areas on which natural enemies are applied in greenhouses

year	Encar.	Phyto.	leafm. paras.	Bacil.	Amblys.	Aphid.	Asch/Vert.
1968		13					
1969		30					
1970	115	218					
1971	128	110					
1972	144	157					
1973	286	262					
1974	561	241					
1975	690	312					
1976	1070	677					
1977	1223	829					
1978	1144	908				3	
1979	1233	978	3		1	7	88
1980	1181	943	32		1	7	1
1981	1161	1016	38		23	9	26
1982	1087	1022	10		35	7	
1983	1231	1167	33	400	10	7	48
1984	1410	1227	41	561	28	13	
1985	1600	1300	460	875	65	13	
1986					140		

Table 2.

Biological control in greenhouses, summary of activities developed since 1968 (mainly in Western Europe)

		1968	1970	1973	1976	1979	1982	1985
Number of natural enemy producers		1	1	2	5	5	15	15
Number of countries with application of:	Pest aimed at:							
Encarsia	whitefly		3	3	9	11	15	18
Phytoseiulus	spidermite	2	2	3	11	11	15	18
Aphidoletes	aphid					1	1	2
Dacnusa/Opius/ Diglyphus	leafminer					1	3	8
Amblyseius	thrips						1	3
Verticillium	aphid/whitefly						1	1
Area (ha) on which application occurs		10	325	540	1600	2040	2260	3000

3. Factors limiting biological control

It would be unrealistic to regard the greenhouse story as complete. If the greenhouse area on which biological control is currently applied (3000 ha) is compared with the total world area (100.000-150.000 ha), we may conclude that much still remains to be done. The causes that limit application are mentioned below; most of these are also valid for other biological control programs.

3.1. Causes that make application of biological control unnecessary or impossible.

3.1.1. In greenhouses with a certain crop some pests do not always occur, or occur so late in the season that control measures are not necessary.
3.1.2. Biological control in ornamentels is impossible because of a zero tolerance (50% of greenhouse area).
3.1.3. Natural enemies can be efficient in one crop, but not in another (pest develops too fast, natural enemy is hampered etc).
3.1.4. Climatological reasons may make use of elsewhere successful natural enemies impossible.
3.1.5. Integration with chemicals applied against other pests is still impossible.

Based on these limitations I estimate biological control could be applied on about 20.000 ha of the total greenhouse area. With the development of more selective pesticides and/or other control techniques, a much larger area will be available.

3.2. Factors that limit application in crops where biological control seems feasible.

A number of other factors result in a not optimal application of biocontrol, viz. the quantity and quality of natural enemies that are available and the service that growers may obtain from the producer and/or extension service. These problems usually do not occur in countries with large, concentrated greenhouse areas. In the Netherlands, for example, the large greenhouse areas attract a number of supporting industries and organizations (auctions, growers study groups, extension service, glasshouse factories, fertilizer and pesticide companies, producer of natural enemies, research station, etc.). An intensive network of interrelations exists in which information and use of biological control is also integrated. Most of these companies supply guidance together with selling their products. This guidance can be given for a low price because the distances between growers and companies are so small, or growers are visited for other reasons anyway. It is common that salesmen of the natural enemy producer visit the grower frequently to check pest and natural enemy developments, and to inform the grower about integration with pesticides. If such large greenhouse areas do not exist, the growers are insufficiently guided by the natural enemy producer or by extension people. Natural enemies are sent by postal service and this may result in:

3.2.1. a too low number of the natural enemies on arrival,
3.2.2. a bad condition of the natural enemies on arrival,
3.2.3. introduction of natural enemies at the wrong moment,

3.2.4. because of lack of information and guidance the growers do not know how to check and evaluate pest and natural enemy symptoms and therefore corrections of mistakes due to wrong timing are not made or made too late,

3.2.5. further, the grower may use pesticides that are not suitable for integrated control and exterminate his natural enemies by applying one of these pesticides.

Our experience is that good guidance is a first condition for application of biocontrol to be successful. Failures due to causes mentioned in this paragraph are not necessary and usually influence application of biocontrol very negatively.

3.3. Other factors that hamper application are:

3.3.1. The total system of application may become too complicated for a grower. If more than three different species of natural enemies have to be applied and checked in one crop, the method may lose the attraction it now has for growers of greenhouse crops.

3.3.2. The fast changing situation on the pesticides market regularly creates difficulties for application of biocontrol. Usually negative effects of new pesticides on natural enemies are not being studied before such a pesticide replaces an old one, but we hope that this will change in the near future, as a result of the activities of the I.O.B.C. working group on 'Pesticides and Beneficial Arthropods'.

3.3.3. Many growers already using biocontrol methods ask for similar procedures to control other pests. Limiting is the amount of research for development of new methods. The biological control industry is still too small to invest in basic research. Research possibilities have to be provided by (semi) governmental institutions. Other ways in which the government could increase the application of biocontrol are education and training of extension officers and better checking of the correct use of pesticide applications.

4. Suggestions for discussion

Is the list with areas and natural enemies in table 1 and 2 complete?
Is the list of limiting factors complete?
What are the factors preventing application of biological control in your country and how can the situation be improved?

EVALUATION OF NATURAL ENEMIES PRIOR TO INTRODUCTION

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1. Introduction

Many evaluation programs of natural enemies are characterized by an ad hoc type of research, very limited funding and time, and they are therefore doomed to fail. Most, if not all, natural enemies presently used for control of pests in greenhouses have been found by luck or in a "trial-and-error" way of work. Finding and effective natural enemy is a laorious task. The empirical method has forced researchers to think about ways of optimizing research so as to increase the predictibility of success before introductions are made. But even experienced workers in this field still express strongly opposing opinions on the value of such pre-introduction studies. For a description of these opposing views I refer to Van Lenteren 1980, 1983, 1986a & b. It suffices to state here that the much criticized emperical method leads to results that are contrasting positively with results obtained by the chemical industry, which, by the way, uses exactly the same empirical method. To date, sources for natural enemies seem to be much richer than sourches for chemical pesticides. The success ratio in biological control is one out of 100, whereas it is only one out of 10000 in chemical control. The period from starting to look for a new pesticide, whether a chemical or biological agent, is circa 10 years. Risks of resistance are neglectable in biological control, specificity is large and harmful side-effects are very few. A serious drawback for producers of natural enemies is their specificity: although environmentalists regard this as one of the very positive points, control specialists would appreciate somewhat broader working spectra. The practical situation now is: one natural enemy species for one pest species. For a further discussion of this topic I refer to Van Lenteren 1986a & b.

In this article I propose a more coherent way of evaluating natural enemies, which might lead to predictability of the quality of natural enemies and which would provide at least a way of comparing qualities of different natural enemies.

2.Planning of a project

The usual way in which a classical biological control project is tackled is as follows (Zwoelfer et al. 1976). The taxonomic

and noxious status of the target organism are defined and information on the pest is collected and evaluated. If an appropriate biological control agent is not available, an area for collection of natural enemies is selected and an inventory research can be started. A broad inventory, including pertinent ecological details (e.g. hyperparasitic habits and host range) should be completed before detailed studies begin.
With these data a comparative analysis of natural factors influencing pest numbers can be made. The results of such investigations do not provide predictions for success, but they can help to discover whether an agent is clearly unsuitable. After this first selection characteristics listed in table 1 are studied. Based on these studies a selection of agents for introduction can be made. The selected material is prepared for shipment and the natural enemies are released in the area were the pest has to be controlled. After release a final evaluation of the effectiveness has to be made in the target area.

3.Types of biological control

What has to be studied prior to release partly depends on the type of biological control program one develops. Natural enemies are used in different ways, presently we distinguish three release methods:
(a) Inoculative release method (or classical method). Natural enemies are collected in an exploration area and introduced in the pest areas. Only a limited number of organisms is released, the aim is a long-term effect. This method is generally applied against pests in forest and orchard ecosystems.
(b) Inundative release method. Natural enemies are collected, mass reared and periodically released in large numbers to obtain an immediate effect. This method is used against univoltine pests in annual crops.
(c) Seasonal inoculative release method. Natural enemies are collected, mass reared and periodically released in relatively large numbers in short-term crops (6-9 months) where multivoltine pests occur. The relatively large number of natural enemies is released to obtain both an immediate control effect and a build up of a natural enemy population for control later during the same season.

Table 1. Citeria for pre-introductory evaluation of natural enemies

	release program		
		seasonal	
criterion	inocul.	inocul.	inundat.
1. seasonal synchronization with host	+	-	-
2. internal synchronization with host	+	+	-
3. climatic adaptation	+	+	+
4. no negative effects	+	+	+
5. good culture method	-	+	+
6. host specificity	+	-	-
7. great reproductive potential	+	+	-
8. good density responsiveness	+	+	+/-

+=important -=not important

4. Criteria for pre-introductory evaluation

Natural enemies should satisfy more conditions of table 1 to be successful in an inoculative release program than in the other two programs. The attributes listed in the table seem necessary for good control, but they are clearly not sufficient. Furthermore, several of these criteria are not absolute but are only meaningful in comparison to values for other natural enemies (criteria 5 to 8). Density responsiveness seems to be the most difficult to determine. The central idea behind theoretical explanations for successful biological control has been that efficient natural enemies operate by creating a stable pest-enemy equilibrium at low densities (Waage & Hassell, 1982). Recently Murdoch et al.(1984, 1985) challenged the central role of a low stable equilibrium. If one believes biological control to be either a stable pest-enemy equilibrium proces, or a stochastic non-equilibrium process, different criteria are important during evaluation of natural enemies (van Lenteren, 1986b). As there is yet no answer to the working mechanism of biological control, I propose to study only the unequivocal criteria 2,3,4,5 and 7 for natural enemies to be used in greenhouse situations. A motivation for this choice is given below.

(1) seasonal synchronization of the natural enemy with its host is not important: it can be obtained by the grower through a timely release of natural enemies

(2) the ability of the natural enemy to devolop in the host is essential for ongoing control, a synchronization between development of pest and natural enemy is important at the start of the season when generations are still discrete

(3) at an early stage of research it should be tested whether the natural enemies are able to develop, reproduce and migrate given the climate conditions under which they are to be used

(4) natural enemies should not attack other beneficial organisms or non-pest organisms in the area where they are to be introduced

(5) good culture methods for natural enemies are the basis for a successful greenhouse biological control programme

(6) in greenhouses usually only one potential host of a natural enemy occurs, so host specificity is not of crucial importance

(7) it is frequently stated in the literature that natural enemies should have a potential maximum rate of population increase (or killing power) equal to or larger than that of the pest. This seems to be a logical premise in seasonal inoculative programs

(8) good density responsiveness is also a necessity, but the difficulty of measuring it leads to the conclusion that testing density responsiveness is unpractical under laboratory conditions.

The sequence in which we study the criteria is given in figure 1. The most problematic part is in the tail of the figure: to test whether a natural enemy is able to reduce and suppress the pest sufficiently at greenhouse conditions. The state of affairs is that we have to rely on (expensive) experiments in greenhouses.

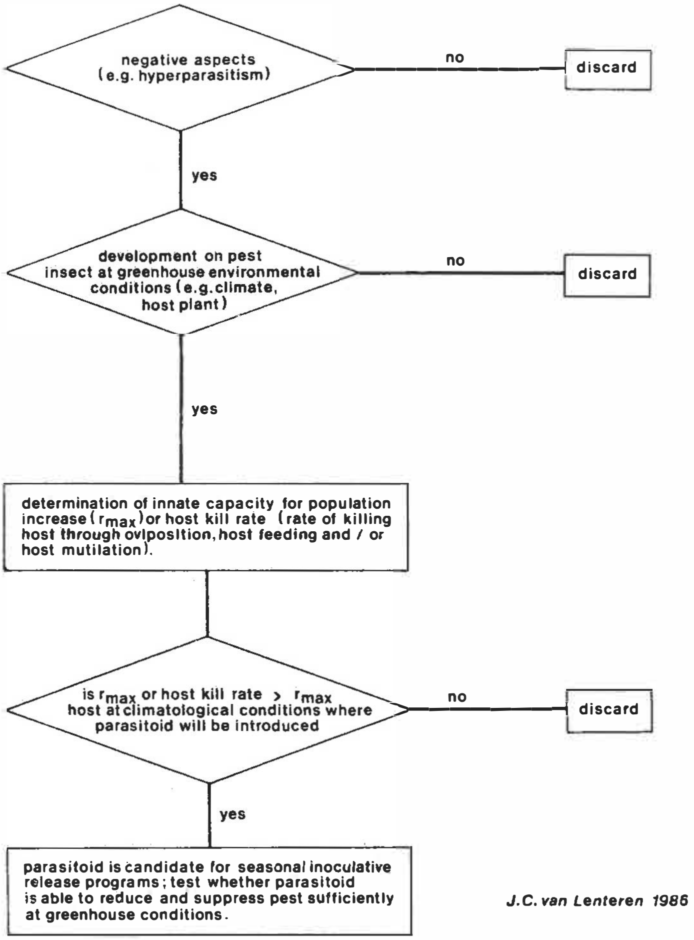

Figure 1. Flow diagram depicting an evaluation programme for natural enemies to be used in seasonal inoculative release systems.

5. Future research

Continuation of development of pre-introductory evaluation programs. Testing of such programs with data from basic ecological research and practical evaluations in greenhouses.

6. Suggestions for discussion

Why are pre-introductory evaluation programs so little used? Is it because of the low predictive value, because of the incompleteness of the program, or because of the still immature stage of western-european biological control research?
Could we come to agreement about an evaluation program to be used in the future, if it were only for making comparisons of natural enemies tested by different groups easier?

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Encarsia formosa can control greenhouse whitefly at low temperature regimes.

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1. Introduction

The parasitic wasp Encarsia formosa Gahan is presently used on 1700 ha in 20 countries to control the greenhouse whitefly Trialeurodes vaporariorum (Westwood)(van Lenteren 1985). Because of high energy consumption in greenhouses, research is under way to develop crops that produce well at lower temperatures than used until now. At the end of the seventies it was expected that new temperature regimes for growing tomato would be 7 C at night and 18 C by day; they were then 18 C at night and 22 C by day. These new low temperature regimes have not been realized yet, simply because insulation of greenhouses resulted in a considerable saving of energy and energy costs increased less than expected. Presently night temperatures in December, January and February are around 15 C, and day temperatures vary between 18 and 22 C. After February night and day temperatures are higher (Ravensberg et al. 1983). In relationship with the ideas to lower temperature regimes, we decided in 1979 to start a search for new natural enemies of the greenhouse whitefly (parasites, predators and pathogens) because data from the literature indicated that:

- at temperatures below 20 C the intrinsic rate of increase for E.formosa is lower than that of whitefly; above 20 C the situation is the reverse (data for tomato)
- at temperatures below 21 C wasps do not fly and hardly show any activity.

Details on the pre-1979 literature data on E.formosa and greenhouse whitefly can be found in Vet et al.(1980) and in Van

Lenteren & Hulspas-Jordaan (1983).

2. Summary of the evalution program to find natural enemies for whitefly control at low temperature regimes
The research on parasites since 1979 is summarized below. Work on pathogens done at our laboratory by Fransen is reported elsewhere in these proceedings. We have not studied predators.

(a) A search for parasites in Southwestern USA and Europe resulted in 9 primary whitefly parasites and one obligate hyperparasite of E.formosa (Vet & van Lenteren 1981, van Lenteren & Hulspas-Jordaan 1983). From these, five species could be reared successfully in the laboratory.

Table 1. Whitefly parasites collected and evaluated from 1979 to 1985

species	origin	type of parasite	successf. reared
Encarsia formosa	Calif., USA	primary	yes
Encarsia sp. near meritoria	Calif., USA	primary	yes
Encarsia pergandiella	Calif., USA	primary + hyper	yes
Encarsia tricolor	Spain	primary	yes
Eretmocerus sp. near haldemani	Calif., USA	primary	no
Eretmocerus californicus	Calif., USA	primary	no
Eretmocerus sp. near clauseni	Calif., USA	primary	yes
Euderomphale flavimedia	Calif., USA	primary	no
Prospaltella peltata	Calif., USA	primary	no
Signiphora coquilletti	Calif., USA	obligate hyper	yes

(b) The temperature threshold for oviposition for three whitefly parasites is 12 C: E.formosa, E.pergandiella and E.tricolor show their complete host-searching and oviposition behavioural repertoir at this temperature (van Lenteren & van der Schaal 1981).

(c) The extrapolated threshold temperature for egg maturation is 2 C, which means that between 2 and 12 C eggs are maturing that cannot be laid (van Vianen & van Lenteren 1986).

(d) The pre-1979 data on fecundity of E.formosa are incorrect. As an example some pre- and post-1979 data are presented in table 2. Literature sources and a complete survey of data is given in Van Lenteren & Hulspas-Jordaan (1983)

(e) Fecundity of E.formosa at 25 C on tomato has increased from circa 30 in 1949 to 440 in 1982 (this is a joke)

(f) All other parasites (E.pergandiella, E.tricolor, E.sp.near meritoria and Eretmocerus sp.) performed considerably less well than E.formosa.

(g) As far as the intrinsic rate of increase concerns, no problems for whitefly control at low temperatures should occur: the r-values for E.formosa are at all temperatures higher than those for T.vaporariorum.

Table 2. Intrinsic rate of increase of Trialeurodes vaporariorum (T.v.) and Encarsia formosa (E.f.) at low and high temperatures, pre- and post-1979.

species	temp (C)	developmental period (days)	longevity (days)	fecundity	r	period
T.v.	12	64	36	20	0.04	pre-1979
T.v.**	12	60	42	62	0.06	post
E.F	15	52	31	16	0.04	pre
E.F.**	12	40	28	85	0.09	post
T.v.	24	25	17	62	0.14	pre
E.f.	24	17	16	33	0.16	pre
E.f.	25	16	37	442	0.27	post

**=determined at temperature regime of 7 C at night and 18 C by day

(h) Research on the migration capacity of E.formosa at low temperatures showed that:

- freshly emerged females which had developed at 13 C were able to fly at 17 C within 30 min after the vial containing these females was opened (Christochowitz et al. 1981), and
- females released in a greenhouse started to fly at temperatures as low as 13 C and migration was very common at 17-18 C (van der Laan et al. 1982).

So, also the new data on migration capacity of E.formosa at low temperatures point in the direction that control of whitefly should be possible even at low temperatures.

(i) Recently we did an experiment in a greenhouse under practical growing conditions. The greenhouse contained a tomato crop and had a temperature regime of 7 C at night and 18 C by day. Twice the normal number of E.formosa was introduced by doubling the number of introduction sites, while keeping the number of parasites per site (circa 60) and the number of introductions (4) the same as in commercial greenhouses. This means that on average 4x2 instead of 4x1 E.formosa were released per plant. The E.formosa population developed faster than the whitefly population and the percentage parasitism was high (between 60 and 86 %). E.formosa turned out to migrate well at the low temperature regime (Hulspas-Jordaan et al. 1986).

(j) Successful biological control of greenhouse whitefly with E.formosa is very well possible at temperature regimes as low as 7 C at night and 18 C by day, and is economically no problem.

3. Future research

This project has been finished. The data will be used to show the usefullnes of the innate capacity for increase as a criterion to evaluate natural enemies.

4. Suggestions for discussion

How should natural enemies be compared in order to come up with reliable judgements about their quality?
Can we conclude now that E.formosa is able to control whitefly at low greenhouse temperatures and that failure of control at low temperatures is not due to inefficiency of E.formosa but to other causes like e.g. a too high whitefly population before E.formosa was introduced?
Should, for temperature regimes between 7N/18D and 20N/30D, any work be done on other natural enemies for control of whitefly in tomato, as we have shown now that E.formosa is effective at these conditions and economically the most profitable?

5. Acknowledgements

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Leaf hairs, Encarsia formosa and biological control of whitefly on cucumber

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1. Introduction

Control of whitefly (Trialeurodes vaporariorum (Westwood)) with Encarsia formosa Gahan is easy on tomatoes (Vet et al. 1980) but unsatisfactory on cucumbers (Woets 1978). The failure of control on cucumber may be due to several causes, the most important are the very good host-plant quality for whitefly (van Boxtel et al. 1978; van Lenteren et al. 1977) and the many relatively large hairs on the leaf hampering movement of E.formosa (Hulspas-Jordaan and van Lenteren 1978). Furthermore, honeydew is retained on the underside of leaves with hairs. Wasps which become covered with honeydew spend much time in preening their bodies.

Several possibilities for improving the control of whitefly on cucumber have been tried such as:
(a) Searching for resistance in cucumber. This has not yet resulted in finding cucumbers (partly) resistant to whitefly.
(b) Searching for other natural enemies. All parasites of whitefly show basically the same host-searching behaviour as E.formosa and are, therefore, expected to be hampered by leaf hairs as well. As the developmental and reproductive characteristics of these parasites are unfavourable compared with those of E.formosa, we do not expect them to be of use (Vet and van Lenteren 1981 and van Lenteren these proceedings). Effective predators of whitefly are unknown. Pathogens like the fungi Aschersonia aleyrodis and Verticillium lecanii show good prospects for a temporal reduction of whitefly numbers and can be used in combination with E.formosa (see Fransen, these proceedings).
(c) Attempting to improve the reproduction capacity of E.formosa. As the reproduction capacity of greenhouse whitefly is much higher on cucumber than on tomato, the innate capacity of population increase for whitefly on cucumber and that of E.formosa are approaching each other. We expect that any increase in the rate of population increase of E.formosa would

help to make the biological control system more reliable. Selection for females with a higher number of ovarioles failed (van Vianen and van Lenteren 1986). Only rearing of E.formosa on another host (Aleyrodes proletella) resulted in females with significantly more ovarioles than in females reared on T.vaporariorum. As rearing on A.proletella is too expensive this line of research has been terminated.

(d) Improving the amount and number of E.formosa introductions. Since several years a number of cucumber growers successfully use E.formosa, but a very careful timing of introductions is necessary as well as a rather high frequency of introductions (circa 8 to 12 two-weekly introductions). The succuss of control is directly related to the intellectuality of the grower and the attention paid by him to development of pest and parasite. These high demands keep us from advising to use E.formosa on a larger scale in cucumbers.

(e) Searching for cucumber varieties with less or no hairs. Circa 200 cucumber cultivars have been examined by De Ponti but none of these appeared to be defenitely less hairy. However De Ponti found a literature reference in which a completely hairless cultivar was mentioned. We obtained seeds of this variety and some of the work done with this variety is reported below.

2. Hairless cucumbers

Hulspas-Jordaan and van Lenteren (1978) compared the walking speed of E.formosa on several glasshouse crops with different leaf structures. It became clear that walking speed was inversely proportional to the degree of hairiness. On cucumber (cv 'IVT no. 71240') numerous hairs on the leaf surface hamper the tiny wasp and reduce its walking speed which makes it more time consuming to find hosts (Milleron 1940; Hulspas-Jordaan and van Lenteren, 1978). The large cucumber hairs also retain a vast amount of honeydew deposited by the whiteflies on the leaves. On smooth leaves the honeydew is sprayed downwards and part of it falls on the upperside of lower leaves. Wasps that have run into a droplet of honeydew drown or have to spend much time (upto a day) in preening their bodies. These observations suggested that on cucumber biological control of whitefly with E.formosa could be improved by reduction of the hairiness. An hairless mutant (cv'IVT no. 761077 Mayak') was introduced into the Netherlands by de Ponti (1984). It appeared, however, that E.formosa was walking so fast on the hairless leaves that they merely walked over whitefly larvae without noticing them. Besides it appeared difficult to breed hairless varieties adapted to Dutch winter conditions. Therefore research was continued with experimental hybrids having a hair density 50% of that of present commercial cultivars. These hybrids can be easily developed as the inheritance of glabrousness appeared to be intermediary (Inggamer and de Ponti 1983).

3. Cucumbers with less-hairy leaves

The average number of leaf hairs on the "normal" cultivar (C+) is higher than that on half-haired cultivars (C1/2), see table. The average walking speed on C+ is significantly lower than on C1/2. Encarsia females are defenitely hampered more on C+ than on C1/2. Also the searching pattern on C+ and C1/2 does differ, parasites turn more on C+ thereby more frequently recrossing their path than on Cl/2. In these experiments the walking speed on C+ is considerably higher than that recorded by Hulspas-Jordaan and van Lenteren (1978). This difference may be attributed to the different ways of measuring the walking tracks (i.e. the distance walked during a 10-seconds period). Hulspas-Jordaan and van Lenteren (1978) used a curvimeter (an apparatus to measure the lengths of curved tracks) with a discriminative power of ca. 2mm and because many of their track parts fell into this category, the average walking speed cannot be calculated as reliable as with our new computerized method. The discriminative power of our x-y digitizer is ca. 0.01 mm.

In a special set-up the encounter probability of a parasite with whitefly larvae and searching time was determined. Individual parasites were released centrally on a leaf. Six whitefly larvae were present equidistantly on an imaginary circle with a radius of 2.5 cm to the release point. The searching activity 199 females was observed: circa 70% of the females found a larva within 1.5 hours. The percentage encounters was insignificantly higher on Cl/2 (74%) than on C+ (62%). The percentage of parasites that failed to find a host and flew away was insignificantly higher on C+ than on Cl/2 (22 and 16%, respectively). The average searching time of the wasps from release till finding a larvae was significantly shorter on Cl/2 (1110 sec) than on C+ (1560 sec). The results indicate that E.formosa females will be able to find more whitefly larvae on less hairy cucumber leaves than on hairy ones in the same amount of time. Tests for host-plant quality for whitefly of all new cucumber varieties used in the experiments show that their quality is not better than that of the normal hairy variety: host-plant acceptance, oviposition frequency, total oviposition, rate of development from egg to adult and mortality are similar. These results are promising but the ultimate conclusion on successfulness of whitefly control with E.formosa in cucucumber can only be obtained fdrom tests under practical conditions in greenhouses.

Table 1. Characteristics of cucumber cultivars and walking speed of E.formosa

cultivar	hairiness	no.hairs per cm2,+/-sd	walking speed mm/10sec +/-sd	no. females tested	no. tracks measured
IVT no. 71240	normal 1978		2.1+/-0.2	15	275
IVT no. 761077	hairless'78		6.3+/-0.9	15	221
cv Farbio	normal '85	382+/-147	3.1+/-0.9	23	241
IVT no 81148	half '85	156+/- 64	4.0+/-1.2	22	220

4. Greenhouse tests

A number of trials to test the importance of hairiness in reducing the parasitization efficiency failed to give conclusice answers. Analysis of these experiments led to the following conclusion. Knowledge of the reproductive dynamics of

E.formosa was essential to be able to develop a proper set-up for testing the effect of hairiness on parasitization effiency. The first set of experiments was done at high whitefly densities (than 50 larvae per leaf). At such high densities differences in degree of hairiness do not result anymore in differences in parasitism: the searching time of the parasite is not the limiting factor, instead the rate of production of parasite eggs and/or the time needed for depositing eggs becomes the limiting factor(s).
Proper set-ups have been developed in the mean time. Half-haired and normally haired cucumbers were only lightly infested with whitefly (10 larvae per plant). Circa 50 plants of each type were placed separately in two greenhouses. One parasite was released per plant. About ten days later the degree of parasitism was determined. In one test the percentage parasitism was significantly higher on the half-haired hybrid (72%) than on the standard variety (58%). Further experiments have to confirm results before half-haired cucumbers will be bred commercially.

5. Future research.

Tests under practical conditions to show an improved effect of reduced hairiness on biological control of whitefly by E.formosa in cucumber crops.

6. Suggestions for discussion

Does breeding for (partial) resistance against pests and diseases also stimulate and help application of biological control?
Should breeding for certain morphological characteristics which improve the efficiency of natural enemies be stimulated?
Where are opportunities in greenhouse crops for similar developments?
How much and what type of (basic) research is necessary to quantify effects of varation in morphological characteristics in the predation and parasitization efficiencies (host-plant quality of plant for pest, reproduction strategy of parasite etc.)

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EFFECTS OF AN OVERHEAD MISTING SYSTEM ON THRIPS POPULATIONS AND SPIDER MITE-PREDATOR INTERACTIONS ON GREENHOUSE CUCUMBER

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Summary

Experiments have been conducted over a 2-year period in four (9 x 13 m) greenhouse compartments containing cucumbers. We wished to measure effects of regular overhead misting on thrips (*Frankliniella occidentalis*) poulations, plus the interactions between spider mites (*Tetranychus urticae*) and the predator *Phytoseiulus persimilis.*

Thrips abundance (assessed by flower extractions, leaf counts and yellow sticky traps) on plants in greenhouse compartments with a regular misting program was significantly lower than on plants in non-misted compartments.

T. urticae - *P. persimilis* interactions were measured on leaves of large plants growing in the greenhouses, as well as on smaller, potted cucumber plants, placed in the greenhouses for 3-5 day periods. On large plants, *T. urticae* were more numerous on apical leaves in non-misted greenhouses, compared with plants under a regular misting regime. *T. urticae* also dispersed more rapidly under the "dryer" conditions. On the small, potted cucumber plants, these differences did not always occur. Total cucumber production was higher in misted greenhouses, but the % of No. 1 grade fruit was not different.

1.1 Introduction

One of the main goals of our greenhouse vegetable crops research program at The Ohio State University is the development of practical integrated pest management (IPM) and/or biological control (BC) programs for tomato and cucumber. This has been stimulated by several factors, including a shortage of registered pesticides, pesticide resistance, phytotoxicity, and the success of IPM and BC programs in Europe and Canada. This paper will present a summary of our present work on cucumber, plans for the future and suggestions for discussion. Major insect and mite pests of cucumber and BC/IPM approaches (if any) are shown in Table 1.

For several years we were limited in our attempts at natural enemy introduction by a lack of reliable suppliers. Recently, this problem has been eased considerably by companies in The Netherlands and Canada. Also, there are U.S. brokers for natural enemies that already have the necessary importation permits, which makes the importation of natural enemies easier.

Although during the past year or two more than 50% of the greenhouse vegetable growing area in Ohio was attempting BC/IPM, there have been setbacks. On cucumber, the problems have been caused by two main pests: thrips and spidermites. *Phytoseiulus* predators are effective in some situations for *T. urticae* control but not in others, mainly related (we assume) to high greenhouse temperatures and late introductions of insufficient numbers of predators. Problems in achieving adequate control of spider mites on cucumbers with *P. persimilis* was mentioned in a previous study by Lindquist (1981). It is not unusual for temperatures to rise well above 30°C in greenhouses during sunny days. These warm temperatures appear to favor spider mites over predators.

Table 1. Major insect and mite pests of greenhouse cucumber in Ohio.

Pest	IPM/BC
Whitefly (*T. vaporariorum*)	*E. formosa* (C)[1/] *V. lecanii* (E)[1/]
Aphid (*A. gossypii*)	*V. lecanii* (E) *A. aphidimyza* (E)
Lepidoptera (*T. ni*)	*B. thuringiensis* (C)
Thrips (*F. occidentalis*)	*A. cucumeris* (E)
Cucumber beetle (*A. vittatum*, *D. undecimpunctata*	-
Spidermite (*T. urticae*)	*P. persimilis* (C)

[1/] C = in commercial use; E = experimental use.

High thrips populations have been a concern to growers because they are associated with large numbers of unmarketable fruits. Also, heavy foliage injury may reduce total yields.

1.2 Description

With the advent of greenhouse climate control capabilities, monitored and adjusted by computer, the potential exists for making the greenhouse environment less favorable for pest development (or more favorable for the natural controls). One of the simplest environmental paramaters that can be modified is moisture, such as relative humidity or leaf wetness. Tulisalo (1976), using an automated sprinkler system, showed that spider mite populations were reduced on cucumbers exposed to sprinkling. We wished to use a similar system in our greenhouses, equipped with a Priva computer, to measure effects on spider mites, *P. persimilis*, and thrips (*F. occidentalis*). Environmental monitoring was done by the computer and a datalogger. Parameters measured by the computer included photosynthetically active radiation (PAR), plus outside and inside temperatures and relative humidities. The datalogger recorded leaf temperatures (via thermocouples), wet and dry bulb temperatures in the greehouse. Four greenhouse compartments (9 x 13 m) were used during each cucumber crop. The misting and non-misting treatments were changed each crop to eliminate any bias in results. The misting system in our experiments differed from Tulisalo's in that it was not triggered by temperature. Our misting system was activated by a light sensor, and operated every 10 minutes (for 10 seconds) during daylight hours. This resulted in leaves remaining wet during the day, with relative humidities above 90%. The non-misted greenhouses had daytime humidities above 50%. Temperature settings were the same in all four compartments; although recorded air temperatures were slightly cooler in misted compartments.

Thrips were monitored by extracting them from flowers, counting on leaves and by placing 5 cm x 5 cm yellow sticky traps at different heights within the crop canopy. Spider mite and spider mite-predator measurements were made on leaves of plants in the producing crop, and by placing small cucumber plants in 10 cm diameter pots into the greenhouses for short time periods.

1.3 Results

1.3.1 Misting apparently makes the greenhouse environment less favorable for spidermites, rather than more favorable for *P. persimilis.* spider mite dispersal vertically on the cucumber plants was much slower in misted greenhouses.

1.3.2 On "producing" plants, spider mite egg production peaked earlier on plants in non-misted greenhouses, but continued longer on plants in misted greenhouses. Total egg production was about the same. Results on potted plants placed in the greenhouses did not always correlate with those growing in soil, indicating that moisture itself may not have directly affected spider mites, but that some effects were plant related (i.e., moisture stress). On potted plants placed between rows of producing cucumbers, there were significantly greater numbers of spider mite eggs laid on plants in non-misted compartments compared with misted plants. When plants were also placed approximately 1.8 m above the surface (i.e., at the height of the producing crop), these differences did not occur.

1.3.3 Misting every second or every third week appears to yield spider mite populations intermediate between those on non-misted plants and those misted daily.

1.3.4 Thrips populations were significantly lower on plants in misted compartments, as measured on flowers, leaves or sticky traps.

1.3.5 More cucumbers were produced in misted compartments, although there were no significant differences in no. 1 grade fruit.

2.1 Future Research

2.1.1 Determine whether a misting system based on accumulated light units is as effective as the present program of constant daytime misting once a certain light level is reached.

2.1.2 Evaluate *Amblyseius* predators in the misting system for biocontrol of thrips.

2.1.3 Work cooperatively with agricultural engineers to develop vertical plant leaf temperature profiles, and compare these with air temperatures. This may help to explain spider mite-predator interactions on apical and subapical leaves.

2.1.4 Work cooperatively with plant pathologists to assess the impact of misting with and without air circulation on various plant pathogens (e.g., *Didymella bryoniae*).

3.1 Questions for Discussion/Ideas for Cooperative Research

3.1.1 The "high-temperature tolerant" strain of *P. persimilis*: Does it exist? Is it necessary? Can control of spider mites be obtained by adjusting introduction rates and methods? How harmful are high temperatures to predators?

3.1.2 Some models for spider mite-predator interaction do not consider behavior differences on different host plants, or plant growth habits. Is this realistic, or should individual host-plants be considered?

3.1.3 what are the economics of using *Amblyseius* predators for thrips control on cucumber?

3.1.4 What are the possibilities for microbial control of thrips? Are there opportunities for cooperative research in this area?

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BIOLOGICAL CONTROL OF PESTS AND DISEASES IN GLASSHOUSES IN BULGARIA - TODAY AND IN THE FUTURE

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Summary

Since 1980 the area under glasshouse vegetable crops with biological control of pests has been annually increasing. This method was applied at 81,45% of the total area under glass. The predator Phytoseiulus persimilis is applied successfully against spider mites. When the damage is negligeable and the density is 5-6 mites per leaf in cucumbers the predator is colonized in the ratio of 1:20. In tomato and pepper plants with 2-3 mites per leaf the predator is released in 1:10. A population of phytoseiulus is bred resistant to organophosphorous compounds, which is used in practice. The parasite Encarsia formosa is applied against glasshouse whitefly (Trialeurodes vaporariorum Westw.) - 5-8 individuals per tomato plant and 10-14 per cucumber plant. A parasite introduction begins when 0,3-0,5 adults per plant are established. Phytoseiulus and encarsia as well are applied as a part of the integrated system combining different methods and means of pest control.

The first trials of practical application are started with Trichoderma fungi, showing high antagonistic activity against soil pathogenes as a cause of some diseases of vegetable crops under glass.

1.1 Introduction

Growing vegetable crops under cover provides for all-year-round plant production. Alongside with this conditions are created for closing the life-cycle of some pests, including spider mites (Tetranychus urticae Koch., Tetranychus turkestani Uvar.-Nik., Tetranychus cinnabarinus Boisduval) and the whitefly (Trialeurodes vaporariorum Westw.) being of the greatest economical importance. The conventional system of their control incorporates numerous and frequent applications of chemicals. Often pesticide treatments over a vegetation period are more than 28-30. Due to the ability of these pests to breed rapidly resistant populations the chemical control proves ineffective. Therefore, biological control is required together with the other methods in the integrated control system.

Studies on Encarsia formosa Gah. in Bulgaria began in 1964 and those on the predator mite Phytoseiulus persimilis A.-H. - in 1967 (Christova, 1971). Nevertheless the application of these bioagents in the greenhouse practice untill 1980 was not totally restricted. The establishment of suitable bases for their mass production enables the broader scale application of encarsia, as well as phytoseiulus.

Some diseases caused by soil pathogenes occur on the vegetable plants in greenhouses. Because of the energy crisis the yearly soil steaming is not advisible. Chemical application is disadvantageous too from economical, ecological and biological point of view. Therefore suitable biological means are sought after. There are some records in literature on the successful application of Trichoderma genus strains in the control of various kinds of the Fusarium fungi (14).

1.2 Spider mites

Until 1980 the application of phytoseiulus in the control of spider mites was restricted by the intensive chemical control of whitefly. The introduction of encarsia enabled the exhibition of efficiency by the predator.

The occurrence and rate of multiplication of Tetranychus mites in the greenhouse varies with the time and the crop (6). Thus differentiated rates of phytoseiulus application have been developed according to the crop, pest density and temperature and moisture conditions in the glasshouses. Phytoseiulus is effective when introduced in predator/host ratio of 1:20, under conditions of slightly injured cucumber plants with 5-6 tetranychid individuals per leaf and 20% of leaf-damage (1). The predator is released in the ratio of 1:10 on tomato and pepper plants when the average density of pest is 2-3 individuals per leaf (3, 4).

The greenhouse growing of ornamentals provides relatively unfavourable conditions for predatory mite, thus, economical efficiency can be achieved by increased rates of release. Per sq. m, occupied by cala-lily and carnation, 50-60 predators are released. Roses are grown under conditions of lower temperature and relative humidity so the number of introduced predators is 150 per sq. m (5).

The energy problem and the growing of vegetables under conditions of reduced heating regime reflect on the population dynamics of spider mites as well as on the phytoseiulus effectivity. It is being exhibited 7-10 days after the release instead of 5 days. When the temperature and humidity conditions are of great fluctuations, the rates are increased by 20% and two- and threefold release is undertaken.

When the biomaterial has been stored for more than a week, the release rate is also increased by 20-25% (6, 7).

At higher initial density of the host the predator is colonized only after preliminary reduction of pest population by selective acaricides.

A phytoseiulus strain resistant to organophosphorous pesticides has been bred and applied in the biocontrol. It provides a broader area of its application in the integrated control (2).

It is found out that after acaricidal treatment of greenhouse crops the spider mites population is recovered more rapidly than after phytoseiulus application (2).

1.3 Glasshouse whitefly

In Bulgaria the parasite encarsia has proved its high effectivity long years ago (8) and recently it is applied on a larger scale in the practice.

The parasite should be introduced into the greenhouse at low density of adult whitefly individuals - 0,3-0,5 individuals per plant (12). In practice the first encarsia sample is introduced after the appearance of adult whitefly individuals.

Biomaterial quantity and number of introductions depend on the host-plant, pest density and the temperature and moisture in the greenhouse. Good result has been obtained with tomatoes when 5-8 individuals of encarsia are released per plant after 4-5-fold distribution in intervals of 10-14 days (12). The parasites are released in greater quantities on cucumber since it is a more favourable whitefly-host and a more unfavourable host for encarsia, namely 10-14 individuals per plant weekly, 7-8-fold release. At a fixed availability of 14 parasites per plant and different initial density, when the first adults are recorded, 0,5, 1 and 2 whiteflies per plant - at the end of vegetation period the number of parasitised scales reaches 97,6, 95,4, 95,0 and 88,3% respectively. When whitefly density grows over 1 adult per plant, foliage and fruits are covered with sooty mould.

A great number of pesticides are tested and their side effect on the parasite is estimated with the purpose of integrating the biological agent with the chemicals for disease and pest control (11).

The increase in the area of encarsia application arises the need of increased biomaterial production as well as of greater possibilities for its storage at low temperature. It is found that the material can be stored at 8-9°C for a period not more than 30 days (10).

1.4 Soil phytopathogenic microorganisms

The antagonistic activity of Trichoderma fungi has been studied quite recently in Bulgaria. Since 1980 experiments are carried out on their laboratory and glasshouse application for the control of soil phytopathogenic microorganisms on vegetable and flower crops (9). It was screened 11 strains of antagonistic activity to Fusarium solani f. sp. cucurbitae, causing root-rot of cucumbers. They belong to three species: Trichoderma lignorum, Tr. viride, Tr. koningii.

In 1985 the two strains of the highest effectivity have been tested on 1,5 ha of cucumbers in the practice. Two grams of the most active strain have been released per each plant (1 g contains 2.10^9 spores) wich has lead to 6-fold reduction of injured plants, compared to the control, and 3,5-fold reduction, compared to topsin-M application.

1.5 Application of the biological control in the practice

Since 1980 there is an yearly increase in the area of phytoseiulus and encarsia (Table 1).

Table 1 Use of biological control on glasshouse crops

year	total area under glass (ha)	crop	E. formosa (ha)	P. persimilis (ha)
1981	654	tomato	1,5	-
1982	678	tomato	5	-
		cucumber	1	1
		flowers	-	1
1983	675	no data		
1984	657	tomato	7,5	-
		cucumber	4,5	4,5
		pepper	-	3
1985	691	tomato	19,5	-
		cucumber	9,5	9,5
		flowers	-	1
1986	681	tomato	378	-
		cucumber	176	176

The biological method alone can not control the spider mites and the whitefly due to a number of biological and ecological characteristics, related to the microclimate conditions for pest multiplication in a high density. The biological method is an element of the integrated control system, including different methods and measures: strict prophylactics; organizing and agrotechnical measures; reducing the initial density by 2-fold treatment of seedlings with vydate; usage of yellow sticky traps; application of biological agents and usage of selective pesticides.

The application of phytoseiulus in the integrated systems is successfully combined with the usage of bayleton, benlate, bromex, dimilin, karathane, kelthane, morestan, pirimor, perocin, ronilan, rospin, sayfos, sulphur, thiozol, tedion, torque, zineb. As for encarsia there is the possibility of its integration with acrex, antracol, bayleton, benlate, dithane M-45, daconil, difolatan, dipel, decis, endodan, isathrin, cropotex, morestan, nimrod, perocin, previcur, rovral, ronilan, rubigan, sumilex, topsin-M, thiozol.

1.6 Other pests and future tendencies

The phytoseiulus and encarsia introduction minimizes the usage of pesticides. Meanwhile problems arise, caused by the other greenhouse pests. Aphids are controled with pirimor. The parasite Aphidius matricariae has demonstrated high effectivity against Myzodes persicae and Aphis nasturtii in a ratio of 1:10 to 1:15 (13). Good results are obtained in the control of caterpillars by dipel. The tomato leaf-miner and the tobacco thrips offer a serious problem because there are no effective biological agents for their control (Table 2). A certain effect against thrips is exhibited by the predatory Macrolophus bugs but they can not account for the complete control of pest density.

Table 2 Status of biological method for pest control, 1986

Pest	biological agent as applied in practice	biological agent in experimental phase
Trialeurodes vaporariorum	Encarsia formosa	Ashersonia sp. Verticillium lecanii Macrolophus sp.
Tetranychus urticae, T.turkestani	Phytoseiulus persimilis	-
Myzodes persicae, Aphis nasturtii	-	Aphidius matricariae Verticillium lecanii
Plusia gamma	Bac. thuringiensis	-
Thrips tabaci	-	Macrolophus sp.
Liriomyza bryoniae	-	-

The future activities in the field of the biological method should include the investigation and establishment of highly effective agents of biological control of other pests, the development of methods for a large-scale production and their including in the integrated control system. Another important topic is the improvement of whitefly and spider-mite control through the involvment of new bioagents, or more rational and effective application of the commonly used means of control.

1.7 Suggestions for discussion and ideas for cooperation

A discussion of following topics would be quite useful at the meeting of EPRS-WPRS/IOBC: collection and methods of encarsia and phytoseiulus distribution; economical threshhold of pests and biological control; compatibility between the yellow sticky traps and encarsia; behavior of predators after being introduced into the greenhouse; methods for the mass-rearing of aphids parasites.

The meeting can discuss some questions on research cooperation: development of new methods for avoiding crop invasion by mites; improvement of the methods for commercial production of phytoseiulus; breeding for draught resistant phytoseiulus strain; breeding of vegetable cultivars resistant towards the pests; breeding of encarsia for low temperature resistance; exchange of zoophags and entomopathogenic microorganisms; development of methods for deep cultivation of trichoderma in liquid medium; methods for leaf-miner parasites rearing.

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PERSPECTIVES FOR THE USE OF A PREDACEOUS BUG **MACROLOPHUS CALIGINOSUS** WAGNER (HETEROPTERA, MIRIDAE) ON GLASSHOUSES CROPS.

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Summary

In order to obtain informations about the predatory capacity of the Mirid bug **Macrolophus caliginosus** WAGNER, we began three years ago preliminary experiments in glasshouses. We got some informations about the predator-prey ratio to use and the main behaviour of the bug. The population dynamics of **M. caliginosus** and its prey **Trialeurodes vaporariorum** WESTWOOD was followed in different conditions.

The development of integrated control in the glasshouses of the south east of France during the last years allowed an increase of indigenous predators which seems able in some conditions to control the populations of some important pests, like the greenhouse whitefly, **Trialeurodes vaporariorum** WESTWOOD. One of these predators, **Macrolophus caliginosus** WAGNER a mirid bug, appears in many untreated glasshouses of the mediterranean region. Several works have already showed the interest of such predators in the control of glasshouses pests, particularly against the whitefly (BRZEZINSKI, 1982; EKBOM, 1981; KAJITA, 1982 and 1983; KHRISTOVA and al., 1975).

The main biological characteristics of **M. caliginosus** have been studied in laboratory conditions (FAUVEL, MALAUSA and KASPAR, in press). These predators are non-specific and feed on whitefly, spider mites and aphids. They are very dependent of the plant for egg-laying, the eggs being inserted in the young stems and the leaf-stalk tissues, and occasionally for feeding. Contrary to some other species of mirid predatory bugs, damages to the plant have never been observed, even when the populations were very high. These insects occur naturally on solanaceous crops of tomatoes and egg-plants but we demonstrate that in laboratory conditions, **M. caliginosus** can lay eggs on other plant families.

With the view to use this predator in glasshouses, we began three years ago, to study the population dynamics of the predator and one of its prey, **T. vaporariorum**. These preliminary trials point out the main problems that have to be studied.

The first release experiments showed that the predator-prey ratio necessary to give a good control of the whitefly populations seems to be relatively high, near 1 adult bug to 1 adult whitefly. In such conditions, prey density at planting must be very low. condition always necessary in integrated control in order to reduce the number of natural enemies used. In the same way, the releases must not be done too long after plantation.

But the question is to know if the predator is able to remain in the glasshouse when the prey density is very low. In all our experiments of these last three years, in which the prey density was very low (0.07 to 0.20 adult/plant of tomato), the predators always remained in the glasshouse after the releases and developped well. This seems of interest for the use of **M. caliginosus** in biological control. The different factors that can explain this behaviour have to be studied (dispersion in the glasshouse, feeding activity, phytophagy, resistance to fasting, etc...).

Generally, there are 4 generations of the bug during tomato growing period from february to july in the south of France.

Because of the polyphagy of **M. caliginosus**, it would be necessary in the experiments, to quantify the density of all the potential preys present in the glasshouse if we want to know the predation of the bug. Laboratory studies already showed this polyphagy and the effect of different preys on the biology of the bug (FAUVEL, MALAUSA and KASPAR, in press) and they have to be carried on.

Now, numerous questions have to be studied, but the last observations done in definite experimental conditions allowed to think that **M. caliginosus** could be used as a general predator for the regulation of some glasshouse pests in association with more specific entomophagous insects not always very effective in all conditions (for example in cold glasshouses).

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FAILURES IN BIOLOGICAL CONTROL OF SPIDER MITES - DUE TO PREDATORY MITES OR THEIR USERS?

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Summary

After 15 years of successfully using the predatory mite Phytoseiulus persimilis to control the spider mite Tetranychus urticae, cucumber growers in Finland experienced many failures in control in 1986. This year was also the first when the predators were not produced in Finland but imported from the Netherlands. The reasons for the difficulties were studied, and were found to include the excessive use of the new, "inexpensive" predators by the growers as well as the quality of the predators at the time of introduction into the cucumber stands. Through careful following of the given instructions for use most failures could have been avoided despite the initially inferior quality of the imported predators.

Introduction

Cucumber growers in Finland have since 1970 controlled spider mites biologically with the predatory mite Phytoseiulus persimilis. As a result of three years of reserach it was possible to give the following instructions for use: "The predatory mites are to be spread to the cucumber stand as soon as the first signs of damage have been observed, one predatory mite for 5-10 spider mites. After that the stand has to be monitored weekly, and the predators must be transferred to new, infested spots in the stand as necessary." According to these instructions the growers obtained a balance between the predator and the prey for the whole growing period (Markkula et al. 1972).

Kemira Ltd, a commercial agrochemical company, started to produce and market the predatory mites in 1970. The growers learned quickly to master the technique and have been, according to surveys, for the most part very satisfied with the results. Virtually the only complaints have concerned the price of the predatory mites. In 1985 a dose of 100 predators cost 152 FIM. In other Nordic countries, where the predators are obtained from the Dutch firm Koppert, the price has been less than one tenth of that in Finland.

Kemira produced the predators in Finland, and sent them to the growers in packages of 100 mites. They were sent on bean leaves, together with some spider mites as food for the journey. For the most part they were mature, egg-laying females. Annually Kemira has sold 150 000 - 180 000 predatory mites.

In 1986 two Finnish firms, Kemira Ltd and Schetelig Co. imported all the predatory mites needed in Finland from Koppert in the Netherlands. The predators have been sent in packages of 1000 mites with a week's delivery time at a price of 129,15 FIM per package. The instruction for use was to spread two predatory mites per square metre as soon as "some" spider mites had been noticed. In the instructions it was also stated that it is not beneficial to use more predators, because they will exhaust their food supply quickly and can not reproduce without food - they may also eat their own eggs and juveniles.

The growers eagerly accepted the inexpensive Dutch predatory mites. From the very beginning of the season these were ordered in great quantities. During the whole growing period about 3.5 million predatory mites were used, which averages seven predators per every square metre of the area under cucumber cultivation. This is more than three times the recommended quantity.

The large numbers did not always guarantee a successful control of spider mites. Complete failures and delays in obtaining the control took place clearly more often than previously. On the other hand, most of the growers obtained after the initial delays just as good results as in previous years.

Were the Dutch predators in some respect inferior to those produced by Kemira?

Procedures

Both at Kemira and at Koppert the predators are produced on spider mites grown on bush beans. Kemira sent them to the farmers on bean leaves together with food supply, spider mites, as soon as the order was received. The predators were mature, egg-laying females. The Dutch predators were sent to the growers packed in wheat bran, with a week's delivery time.

Starting from May 1986 at the Department of Pest Investigation of the Agricultural Research Centre, weekly checks of the Dutch mites were done during the growing period. From the samples the number of mites was controlled, their stage of development determined, and the number of eggs and empty sucked spider mites within the bran were calculated. From each sample comparisons were made between the Dutch and Finnish predators for one week on their behaviour and on the beginning of egg-laying and the number of eggs produced. In these isolation experiments all the predatory mites had all the time abundant supply of spider mites at all stages of development.

Results

* In three Dutch samples there were fewer mites than supposed to (= 1000), in two samples 500-600 mites and in one sample only 18 individuals. These samples were from shipments in the middle of the summer.

* All Dutch predators were small and colourless, and over one half were estimated to be juvenile stages.

* The predators had none or only very few spider mites as food along with them - and the shipment was on the way for several days.

* On the first day the predators run around in the isolation chamber and were not at all interested in feeding.

* On the second day they started to feed. First they ate the eggs and juveniles of spider mites, and only after these were exhausted, the mature spider mites.

* On the second day they laid 1-2 eggs.

* On the third day they laid the same amount of eggs as mites produced with the Finnish method.

Discussion

The development and reproduction in *Phytoseiulus persimilis* is affected by many factors:

1. The predator does not reproduce without sufficient food. The egg is up to 50% of the weight of the female, and the mite has no reserves for production of the eggs.
2. Even when there is enough food, the temperature and humidity affect the number of eggs laid as well as the longevity of the female (Pralavorio & Almaguel-Rojas 1979).
3. The development time of the predator is very much affected by the temperature as well as the amount of food (Sabelis 1981, Takafuji & Chant 1976).
4. Sufficient humidity (70% and over) is very important for the reproduction

but the mites feed clearly more under relatively dry conditions than in humid environment (Mori & Chant 1966). If the predator has to stay without food for several days it feeds less than when getting food continuously (Mori & Chant 1966).

5. Already 12 hours without food results in cannibalism, and the predators start to feed on the eggs and juveniles of its own species.

The exact reasons for the failures and/or delays in control when using the Dutch predators will have to be investigated separately for each greenhouse. Probably the most important general reason for the failures has been that the mites have had no food during the transport, and that they have been placed in excessive numbers into stands where they have not had enough food available. Therefore obtaining the balance between the predator and the prey when using the Dutch predators has taken longer than with the "expensive" Finnish predators, which were 1) at a better physiological state when placed into the cucumber stands, and 2) placed in recommended numbers.

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PROGRESS TOWARDS INTEGRATED PEST MANAGEMENT FOR GREENHOUSE CROPS IN NEW ZEALAND

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Summary

IPM for Cymbidium orchids has been developed during the last four years. Implementation of IPM for greenhouse tomatoes is awaiting registration of buprofezin, a selective pesticide for whitefly control, and commercial production of *Encarsia formosa* and *Phytoseiulus persimilis.* IPM for greenhouse roses is being developed but further work on table grapes is dependent on a suitable pesticide for caterpillar control which is harmless to *P. persimilis.* Methods for advisors to assess whitefly and *E. formosa* populations in tomato crops and two-spotted mite and predator populations in Cymbidium orchids have been developed.

1. Introduction

The current research programme started in 1982 when new greenhouse facilities became available and followed a visit to Europe when I saw and discussed many aspects of greenhouse integrated pest management (IPM).

After discussions with New Zealand Ministry of Agriculture and Fisheries Advisory Officers, four crops were chosen; tomatoes (the largest area under cover), Cymbidium orchids (the highest valued export flower crop), greenhouse roses (because of some successful preliminary work) and greenhouse grapes (a promising new export crop). Preliminary observations were made on crop growth and management and on their pests in New Zealand. Two major pests were whitefly, *Trialeurodes vaporariorum* (Westwood) and two-spotted mite, *Tetranychus urticae* Koch. Laboratory colonies of the whitefly parasite *Encarsia formosa* Gahan and two-spotted mite predator *Phytoseiulus persimilis* Athias-Henriot were established from earlier introductions into New Zealand (Martin et al. 1984).

2. Development of Research 1982-1986

2.1 Greenhouse tomatoes

About half the approximately 130 ha of tomatoes grown in greenhouses are in the Auckland region (latitude 37° south). Whitefly survive outdoors in the mild winter climate and the practice of planting in mid to late summer (Feb. to Apr.) results in infestation of most crops from adjacent outside or greenhouse crops. Even crops planted in late winter or early spring usually have whitefly populations too high for *E. formosa* to control. Three key areas for research were initially identified.

a) Whitefly control prior to release of *E. formosa* and selective pesticides harmless to *E. formosa.*

The efficacy of oxamyl applied as granules to the base of tomato plants was demonstrated (Martin and Workman 1984) but this product is not now available in New Zealand. Available products were tested for their ability to control or eliminate whitefly from seedlings and young plants. The systemic insecticides were either ineffective or phytotoxic. The most effective product was a contact synthetic pyrethroid, deltamethrin (20 mg ai per litre), which killed all stages of whitefly (unpublished data) but can be difficult to apply thoroughly to the underside of leaves. Also it is toxic to *E. formosa*. Methomyl can be used successfully to kill adult whitefly and some early instars 3-7 days prior to *E. formosa* release but it has to be used frequently to reduce high whitefly populations. Buprofezin, a promising selective insecticide, can be used prior to the release of *E. formosa* at high or low concentrations depending on whitefly populations. After *Encarsia* is established it can be used at low concentrations, with or without methomyl (Martin and Workman 1986b). Buprofezin is not yet registered for use in New Zealand.

Prior to introducing *Encarsia* there should be fewer than one adult whitefly per ten plants (L. Wardlow pers comm.) and this guideline has been reliable in Auckland. However a simple and quick method was needed to assess the numbers of whitefly pupae and the proportion parasitised. From a study of the horizontal distribution of whitefly pupae at a single level on tomato plants in several greenhouses, the minimum number of leaves to be sampled was determined and a sampling scheme to ensure coverage of the whole greenhouse was devised. The sampling scheme records the presence or absence of whitefly pupae on a leaf and estimates if the proportion of pupae parasitised is less than a predetermined amount (Martin in prep.).

b) Control of leaf and fruit feeding caterpillars

Greenlooper (*Chrysodeixis eriosoma* (Doubleday) (Noctuidae)) can be effectively controlled by three *Bacillus thuringiensis* products (Martin and Workman 1986a).

c) Control of tomato stemborer, *Symmetrischema plaesiosema* (Turner) (Lepidoptera: Gelechiidae)

Tomato stemborer (a native of South America) is a sporadic pest which lives on solanaceous weeds and indigenous plants. The moth can lay eggs on tomato seedlings and larger plants at any time of year which damages the stem at ground level and can kill plants. The efficacy of methomyl applied to the base of the stems has still to be tested.

In New Zealand aphids are an occasional problem and can be controlled with pirimicarb, and two-spotted mite is rarely found on tomato plants.

2.2 *Cymbidium Orchids*

The area of the crop and number of blooms produced has expanded rapidly in recent years. Flowers are exported to Europe, North America and Japan, mainly from July to November. Most orchids are grown in the northern half of the North Island under varing degrees of protection, from shadehouses that are covered with plastic film in the winter to standard glasshouses with heating and automated environmental controls. Four areas for research were identified.

a) Rapid assessment of two-spotted mite and *P. persimilis* populations

We wanted a sampling system or a method of monitoring mite populations which avoided time-consuming mite counting and the need to remove leaves from the plants because Tobacco mosaic virus is very easily transmitted on cutting tools. The greenhouse is divided up into small areas of about 2-3 m^2. Five randomly selected leaves are examined from each area. The proportion of leaves with each mite species is recorded and the patchiness of the mite distribution mapped. No unacceptable flower or plant damage occurs if, in any sample area, no more than 40% of sample leaves during flowering, and 60% of sample leaves during non-flowering have two-spotted mite present.

b) Management of *P. persimilis*

P. persimilis needs to be released more than once a year to achieve the above level of control. In order to detect mite outbreaks early enough for predators to be effective mites must be monitored every two weeks. This is very expensive, but as an alternative, four releases of *P. persimilis* each year 12-14 weeks apart have given satisfactory control of two-spotted mite.

c) Control of aphids, thrips, caterpillars, spiders, the mould mite and bees during flowering.

Most pests that invade the plants during flowering must be controlled by a pesticide that is non-harmful to the flowers, does not leave deposits on the flowers and is safe to P. persimilis. Diazinon emulsifiable concentrate is safe and effective when used every 2 weeks and carbaryl and pirimicarb can be used occasionally for caterpillar and for aphid control respectively. Scale insects are controlled with P. persimilis compatible pesticide during the non-flowering season. Bumble bees (Bombus spp.) can pollinate Cymbidium orchid flowers and cause early senescence. Coarse screens over openings will prevent entry into the greenhouse.

Aphids and thrips are flying in large numbers outside the greenhouse during harvest and can settle on flowers before they are packed. Their detection in Japan can cause fumigation of a whole consignment. An attempt to disinfest boxes of flowers during transit with dichlorvos-impregnated plastic was unsuccessful (Martin and Workman 1985).

d) To establish if the 'mould mite' caused flower damage.

Growers believed mites damage the pollen cap and pollinia, causing the pollen cap to turn brown and flowers to senesce early. Investigations by myself and Dr R. Fullerton (Plant Diseases Division, DSIR) showed that most damage was associated with three different physiological disorders of the pollinia or pollen cap which were associated with particular cultivars. The disorders could be initiated by particular environmental conditions. In a few cases it is likely that the mite, Tyrophagus neiswanderi Johnston and Bruce (Acaridae) pushed under the pollen cap before it was diseased and infected the pollinia with fungus. Some selections of Cymbidium orchid have tighter fitting caps than others and it would be possible to breed for resistance to mite damage.

2.3 Greenhouse Roses

Roses are now the third most valuable export flower crop. Research concentrated on how to manage P. persimilis and how to assess two-spotted mite and the predator (Burgess 1984). The use of fewer P. persimilis per release and a regular release pattern such as for Cymbidium orchids, is now being tested together with a more simple, presence/absence system for assessing mite populations. Some cultivars, e.g. Bridal Pink, appear to be susceptible to whitefly in the spring. A single application of buprofezin (250 mg ai per litre) has given effective control.

2.4 Greenhouse Grapes

The long established, but small greenhouse grape industry was based on a late, black cultivar 'Gros Coleman'. Most of the recently increased production is of the White Muscat cultivar 'Italia' which is grown for export of high quality fruit to Japan. The crop requires intensive management to achieve the necessary high standards. Two main entomological problems were identified.

a) Presence of insects and spiders at harvest

Spiders (mainly black house spider (Ixeuticus martius (Simon))) and longtailed mealy bug (Pseudococcus longispinus (Targioni-Tozzetti)), can be controlled prior to fruit set. Spiders are most effectively controlled just after pruning when the greenhouse is washed down and thoroughly sprayed inside and outside with pirimiphos-methyl or Attack® (a mixture of pirimiphos-methyl and permethrin). The pesticides must achieve direct contact with the spiders to be effective. Mealy bug can be controlled in the first generation by applying a persistent pesticide at bud burst to kill the first instar nymphs before they move on to the leaves, and by systemic pesticides to kill any nymphs that reach the leaves and before they move back into crevices on the stems. Application of a pesticide after flowering is often required.

Because of the continuous threat of invasion by egglaying female leafrollers (Lepidoptera: Tortricidae) pesticides need to be applied regularly from fruit thinning. Pesticides for use between fruit set and harvest must have the following characteristics; leave no deposit on the fruit (i.e. no insoluble powders), not damage the fruit, no chemical residues at harvest, or residues must meet Japanese requirements. No pesticide meeting these requriements is harmless to *P. persimilis.* Attempts were made to control leafrollers using dust formulations of either carbaryl or *Bacillus thuringiensis* but too much dust accumulated on fruit and caterpillar control was inadequate. The young caterpillars feed mainly on the underside of grape leaves and alternative methods for applying powdered pesticides are required which deposit them on these surfaces.

b) Two-spotted mite control.

P. persimilis has adequately controlled two-spotted mite and some have even survived when harmful pesticides have been regularly used. We are now investigating the ability of *P. persimilis* to control two-spotted mite when harmful pesticides are deliberately applied to only part of the grape canopy.

2.5 Other Crops

IPM has been tried experimentally in some other crops, eg capsicums, cucumbers, *Solanum muricatum* and greenhouse strawberries. *P. persimilis* has worked well in strawberries and no thrips damage was found on capsicums. *Phytoseiulus* gives good mite control on *S. muricatum* but permethrin is needed to control fruit boring caterpillars.

2.6 *Encarsia formosa*

E. formosa was introduced from England fifty years ago. The New Zealand strain which has adapted to survive outdoors has a similar number of ovarioles to strains in Europe (Vianen and Lenteren 1982) and a similar susceptibility to pesticides (Walker 1983).

In New Zealand *E. formosa* can be hyperparasitised by *E. pergandiella* How. and precautions must be taken to keep the hyperparasite out of the colony (Martin 1983).

2.7 *Phytoseiulus persimilis*

P. persimilis survives outdoors in the northern half of New Zealand and has been exposed to many pesticides in orchards. A modified IOBC laboratory test was used to assess the susceptibility of the New Zealand strain to pesticides (Bryham 1985). A semifield test has also been developed to assess the effect of pesticides on the ability of *Phytoseiulus* to control two-spotted mite. A programme to select a synthetic pyrethroid resistant strain of *P. persimilis* has been underway since 1982 (Markwick 1986).

3. Future Research

Science funding by the New Zealand Government is being reduced by at least one third over the next few years. Departments are being encouraged to recover the shortfall from the users or beneficiaries of the research. This is particulary difficult and expensive for small industries such as greenhouse vegetable and flower growers especially because they do not have a unified organisation that can organise and allocate research funds.

The future of the greenhouse IPM programmes in New Zealand also depends on establishing commercial production of *P. persimilis* and *E. formosa.* Despite the offer of government subsidies no company with a nationwide presence has decided to take up greenhouse IPM. Several small companies are now negotiating to produce and distribute the parasite and predator. This is also essential for the berryfruit IPM programme.

We plan to quantify the cost advantage of Cymbidium orchid IPM and the potential cost benefits for greenhouse rose IPM, so that a case for financial support can be made directly to the rose growers and flower exporters.

4. Topics for discussion

a) Methods of assessing pest and biological control agent numbers in crops.

Simple and quick methods are needed for use by advisors so that they can answer growers questions and give informal advice. It would be useful to discuss what methods are available and what further research and development is needed.

b) Conservation of pesticides useful for IPM.

Some pesticides are essential for IPM programmes while others make the operation of IPM programmes much easier. An example is buprofezin for whitefly control. The distributors and users need to be encouraged to plan for the long term use and availability of the pesticides.

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EVALUATION OF PARASITIC WASPS FOR THE BIOLOGICAL CONTROL OF LEAFMINERS, LIRIOMYZA SPP., IN GREENHOUSE TOMATOES

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Summary

An aim of our research is to improve the existing biological control method for leafminers, Liriomyza spp., in greenhouse tomatoes. This present method uses seasonal inoculative releases of a parasite, Dacnusa sibirica or Diglyphus isaea. The application of biological control of leafminers last year was not an unqualified success in view of the chemical intervention by a number of growers. Possible causes and solutions are suggested.

A more general goal is the development of a pre-introduction evaluation method for parasites used in a seasonal inoculative release system. Unlike the 'trial and error' method, which is an empirical way to select natural enemies, selection of an effective parasite by the pre-introduction evaluation method is on the basis of a set of criteria. In order to develop the pre-introduction evaluation method, it is important that the results obtained from an evaluation of the effectiveness of different parasite species according to this set of criteria should be compared to the actual control capabilities of the parasites in commercial greenhouses for verification. Preliminary results, for D. isaea in particular, are presented and discussed.

1.1 Introduction

For more than 15 years, the whitefly Trialeurodes vaporariorum, a key pest of greenhouse tomatoes, has been controlled successfully by the parasite Encarsia formosa in ca. 25% of the total production area. Control methods for other insect and mite pests that are compatible with the biological control method for whitefly, are available. Since 1976 the leafminer Liriomyza bryoniae has been present as a potential pest in most greenhouse tomatoes. In 1980 a second leafminer species, L. trifolii, was discovered in vegetables. Chemical control of the Florida leafminer by currently available insecticides is difficult due to resistance problems. Nowadays in greenhouses under integrated control, both leafminers can be controlled effectively by the parasites Dacnusa sibirica or Diglyphus isaea by means of the seasonal inoculative release method. Biological control method by D. sibirica was applied on 60 ha in the Netherlands in 1985 (10,000 - 15,000 parasites per ha; 1 parasite per 2 plants). Natural control of leafminers may occur in the spring, if broad spectrum pesticides are not used and sufficient parasites have overwintered in the greenhouse (Woets and van der Linden, 1982). When there are no parasites present or parasitism is too low after planting, it is necessary to take control measures. Natural control may also occur in the summer when parasites enter the greenhouse from outside through opened windows (mainly D. isaea). Biological control of Liriomyza spp. by parasites was world-widely used on an estimated area of 460 ha in 1985 (for a review, see Minkenberg and van Lenteren, 1986).

1.2 Application of biological control for leafminers

In 1986 biological control of *Liriomyza* spp. was applied on ca. 80 ha of tomatoes and on a smaller scale on sweet peppers, beans, aubergines and gerbera. Although biological control in the latter two crops was satisfactory, the occurrence of the thrips *Frankliniella occidentalis* forced the growers to use insecticides, which ended the integrated control programme. In tomatoes, however, biological control was not always sufficient, because the leafminer population crossed the tolerance level of growers in a lot of greenhouses (Ravensberg, pers. comm.). The remarkably rapid population growth of the pest that year was probably due to a combination of high temperatures in April and interplanting of young tomato plants.

Seven years of experience with releasing parasites in greenhouses has showed that a decrease in the density of the leafminer caused by parasitism will be effected in the third leafminer generation after parasite introduction. Therefore, the parasites should be released in the next leafminer generation after they have first appeared to prevent uncontrollable growth, e.g. due to interplanting. The parasites should be released in January/February because interplanting takes place in April/May and there is approximately one leafminer generation per month. Furthermore, 35 percent parasitism in April does not guarantee sufficient control for the entire season .

For the best results, the parasites should be released throughout the entire greenhouse to prevent host escape and thus uncontrolled growth in certain places (e.g., see Frijters et al., 1986). Secondly, the parasites should be released 4 times, at weekly intervals during one leafminer generation in stead of just once (fig. 1). Otherwise, a part of the leafminer population will escape parasitization, because the immediate effect of the introduction is incomplete and synchronization of the generations imperfect (Westerman and Minkenberg, 1986). The level of control can be improved by introducing the parasites as pupae of different ages attached to cards, which are hung up at appointed places in the plants.

1.3 Development of a pre-introduction evaluation method

The 'trial and error' method, the empirical way to find an effective natural enemy with a minimum of fundamental research, has delivered several commercially applicable biological control methods. One of the disadvantages is that the found effective natural enemy is not always the most effective one; hence, it may not be the most economical control method. Another disadvantage is that estimating control capabilities of natural enemies under greenhouse conditions is extremely difficult, because the variable factors are complex (e.g., interspecific competition) and there is a lack of accurate monitoring techniques and injury levels. Another difficulty of greenhouse research is finding suitable greenhouse situations and growers that will give permission for experiments.

Selection by the pre-introduction evaluation method is based on the characteristics of an effective parasite (van Lenteren, 1980). A parasite is effective when it prevents a pest from crossing the injury level during the entire growing season. The characteristics that are useful as criteria for our selection procedure are: (1) development on the host, (2) side-effects, (3) seasonal synchronization with the host, (4) reproductive potential and (5) density responsiveness. The choice of criteria is determined by the introduction method, i.e. seasonal inoculative releases of parasites (van Lenteren, 1986). We will discuss these criteria successively and with respect to the results of the current research.

1.3.1 Development on the host.

Many parasites that develop successfully are known, 13 species on *L. bryoniae* and 28 species on *L. trifolii* (Minkenberg and van Lenteren, 1986). Our research has been restricted to three species, which parasitize both leafminer species: *Dacnusa sibirica, Diglyphus isaea* and *Chrysocharis parksi*.

1.3.2 Side-effects.

No negative effects, such as hyperparasitism, are known for these three species.

1.3.3 Seasonal synchronization with the host.

For the seasonal inoculative release method, a large number of parasites is released to obtain both an immediate control effect and a build-up of the parasite population for continued control during the rest of the growing season. A perfect synchronization between host and parasite population is necessary, because the host has discrete generations in the spring. If there are no suitable host stages available for parasitization when the adult parasites emerge, a part of the parasite population will die without having parasitized any hosts. At an average temperature of 20°C, the peak emergence of a *D. isaea* population will occur ca. 9 days before the suitable host stage is present (fig. 2).

Host selection in the ectoparasite *D. isaea* was examined by direct observation of female wasps (N = 30) in a two-choice experiment (fig 3). We found that: 1. the mined leaves were visited at random by the parasites, 2. once on the leaf, first instars were found significantly less frequently than older instars, 3. third instars tended to be found faster than younger instars, 4. *D. isaea* preferred to oviposit on third instars, first instars were not parasitized and 5. host feeding took place on all instars. Development of *D. isaea* (N = 8) on second instars of *L. trifolii* was not possible probably due to an inadequate food supply. The endoparasites *Opius pallipes*, *D. sibirica* and *C. parksi* parasitized all instars (Hendrikse et al., 1980; Minkenberg, unpubl.).

1.3.4 Reproductive potential.

The intrinsic rate of increase (r_m) is a suitable index for reproductive potential. The r_m values of *L. trifolii* and its parasite *D. isaea* at three constant temperatures are shown in fig. 4. Over this range of temperatures, typical of greenhouse conditions, and under optimal conditions the population growth of *D. isaea* is much more rapid than the population growth of the leafminer. *D. isaea* develops faster, lives longer and produces more eggs than *L. trifolii*. At higher temperatures, the r_m value of the parasite increases faster than the r_m value of the leafminer. At low temperatures the density of the leafminer population will decrease, because its r_m value is negative below 15°C. *L. trifolii* only thrives at high temperatures. We conclude that *D. isaea* is potentially an effective parasite. So, the r_m value can be useful as (1) a climatic index, (2) to compare the potential population growth of the parasites with the potential population growth of the host, (3) to compare the maximal potential with the actual population growth rate and (4) to compare parasites for control potential.

Values for searching efficiency or migration are not incorporated in the r_m values, which are determined at high leafminer densities.

1.3.5 Density responsiveness.

The density responsiveness criterion is only loosely defined. A useful definition is that the density responsiveness is the portion of the reproductive potential that is realised under the given circumstances. Results on this subject are not available yet.

1.3.6 Verification of the examined criteria.

In order to evaluate the values of the different criteria for each parasite, their control capabilities have to be estimated in commercial greenhouses. We have developed a stratified, at random sampling plan which is accurate and suitable for this purpose. Next year we would like to estimate the control capacities of the different parasites species.

2. Future research

We will continue the research on:

- r_m values of different parasite species
- further development of population-density predictive simulation models
- host searching and host selection by the parasites
- estimation of searching efficiency and density responsiveness of different parasites
- estimation of control capabilities of different parasites in commercial greenhouses
- development of a pre-introduction evaluation method

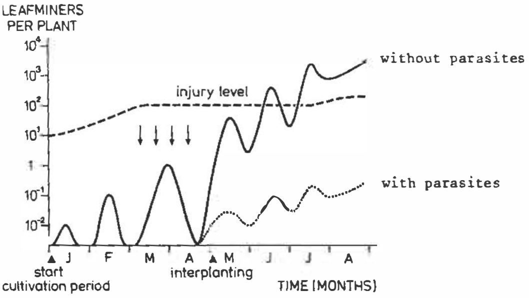

Fig. 1. Seasonal inoculative release of parasites (see arrows) should give an immediate control effect on the leafminer population and a build-up of a parasite population for control later during the same growing season. There are discrete leafminer generations in the beginning of the growing season; the injury level increases during the season.

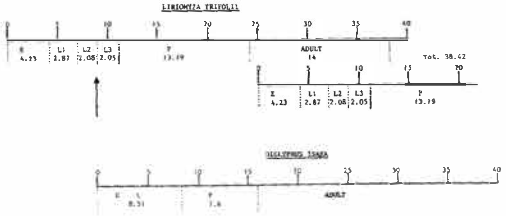

Fig. 2. Comparison of the development time of L. trifolii and of its parasite D. isaea at a constant temperature of 20°C. First parasitization can occur on the third instar (see arrow). The parasites of the next generation have to bridge the period between emergence and appearance of new third instars because of the discrete generations.

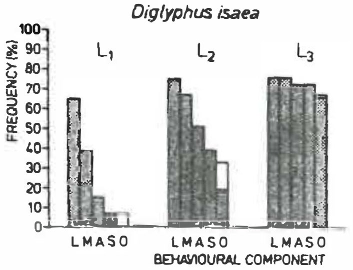

Fig. 3. Host searching and host selection in the parsite D. isaea. The total number of mined leaves offered is 100%. Indicated are contact with leaf (L), with mine (M), antennal contact with host (A), stinging the host (S), ovipositing (O) or host feeding (white part).

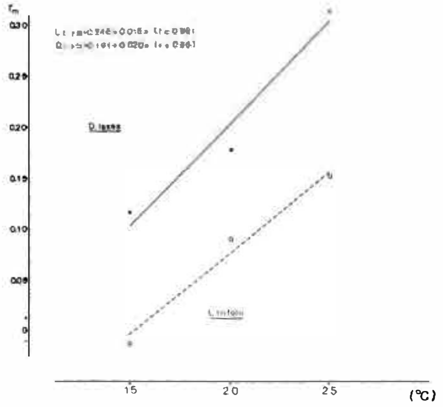

Fig. 4. Comparison of the innate capacity for increase (r_m) of the leafminer L. trifolii and of its parasite D. isaea on tomato at three different constant temperatures.

3. Suggestions for discussion

- should the r_m value of an effective parasite be larger (or equal) to that of the pest? Can the r_m value be an useful selection criterion for evaluation of parasites?
- which are the main factors affecting the population growth of leafminers and how variable are these influences? Can we incorporate these into a simulation model?
- will a simulation programme be of any use for the growers? Can we develop a monitoring programme for the growers so that decisions on control measures can be made on a more scientific basis? Will we be able to predict biological control results in the near future?

4. Biological control

Crop: mainly tomato	country: The Netherlands	year: 1986
	area: 80 ha*	area: 1.5 ha
Pest	practiced	experimental
Liriomyza bryoniae L. trifolii	Dacnusa sibirica	Diglyphus isaea

* Ravensberg, pers. comm.

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ECONOMICAL METHOD FOR MASS REARING OF ENCARSIA FORMOSA

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SUMMARY

Mass rearing of Encarsia formosa requires an efficient host plant. From all tested plants most suitable for Bulgarian glasshouse production proved to be the perennial tobacco species Nicotiana glauca planted permanently in plots.This plant species meets the requirements for efficient cultivation under glasshouse conditions i.e. cultivated all the year round,secures maximum multiplication potentialof the whitefly and its parasite, easily multiplies,is readily manipulated,stored and the parasite population bred on it can be easily purified.Parasite purification is achieved with special gluesticking the parasite on small cardboards or directly on the leaves of N. glauca .The above mentioned glue fixes all pests,including the unparasitized whitefly /larvae and imago /but does not affect Encarsia formosa .The technique for mass rearing of Encarsia formosa is introduced in all larger glasshouses.

1.1.INTRODUCTION

First methods for mass rearing of Encarsia formosa were based on the rigid cyclic recurrence and separate rearing of the host plant,the host insect and the parasite for the sole purpose of obtaining pure and equalized in age biomaterial (Scopes,1971).These methods however demand great deal of manual labour.In recent years therefore it is suggested that Encarsia formosa should be reared upon plant species planted permanently (Zabudskaja,1977;Adam,1979)

Mass rearing of Encarsia formosa entails certain difficulties.The glasshouse whitefly used as host multiplies only upon intensively growing natural hosts. Since the pest is a polyphage it is necessary to choose such plant that can be cultivated easily under glasshouse conditions securing maximum multiplication material for the pest and its parasite and also which can easily be manipulated.Stem of the natural hosts should be strong and upright,having large leaves without any crude structural formations,yet they should be set at different levels.It is very important too that these plant species grow rapidly, so that time,space and labour can be saved. Moreover , these plants should grow tall thus using maximum space.

The multiplication of Encarsia formosa upon larvae of the glasshouse whitefly is associated with ample formation of honeydew. It checks the movements of the parasite and reduces the percentage of the parasitized pests.These consequences can be avoided if foliage of the plants is washed every week with stream of tepid water.Leaves of the plants should be large,smooth,covered with wax layer so that water cannot be retained on them. Still it is necessary that foliage is large and the habitus is not compact.

The best host plant for rearing entomophages ,including Encarsia formosa should also have relative resistance to diseases saving thus treatments with chemical formulations.Moreover there should be used glasshouse species and varieties resistant to easily vectored virus diseases.

In 1980-1983 we carried out investigations in order to determine the most suitable host for the glasshouse whitefly.We tested tomatoes,potatoes,tobacco varieties "White Barley " and "Virginia " eggplants,cucumbers,beans,vegetable marrows,pepper and large-leaved chrysanthemum.

Observation data showed that most suitable hosts for the glasshouse whitefly were cucumbers,beans,vegetable marrows and chrysanthemum.Under glasshouse conditions /mean temperature 23-25 C and humidity about 60-70 %/development of the preimaginal stages of the pest occurs for 19-21 days and lifetime of the imago is about 22-28 days at the time of which females lay 70-110 eggs.The natural death rate of eggs and larvae is not more than 1.9 %.

With the representatives of Solanaceae development of the whitefly is delayed 1 to 5 days,adults live about 20 days and their fecundity ranges between 80 to 110 eggs.The natural death rate varies between 0.9 to 11 %,depending on the phenological state of plants.Imago of the pest when there are no better hosts colonizes also the exponents of this family forming numerous populations.

Pepper proved to be the only unsuitable nutrient plant for the whitefly. Its preimaginal period extends to 40 days,lifetime of adults is shortened to 15 days and its fecundity reduces to 60 eggs per female.The death rate of larvae increases abruptly to 40%.

From all tested plants most suitable proved to be the perennial species of Nicotiana glauca corresponding to the above mentioned requirements.When planted tobacco grows 2.5-3 m high for less than two months, forming more than 30 leaves on the central stem. Tobacco stem is very strong and upright and if cut off the plant develops about 5-6 sprouts and 3 to 4 shoots out of the resting buds, Tobacco leaves are covered with wax layer ,set on long stalks their habitus is not compact.Whitefly and Encarsia are introduced to plants 8-10 days after planting them in plots or even 6-7 days after breaking off the central stem (Natskova,1984).Nicotiana glauca is resistant to anthracnose,powdery mildew as well as to some major virus diseases.

The necessity of great amounts of Encarsia at the time of its releasing and of efficient utilization of the insectarium puts the question for cool storing of the parasite.Experiments showed that the parasite pupae can be stored at 10 C for a month without any increase of the death rate. Since the useful species is kept together with leaves on which host has developed we had to determine which species endured best storage conditions.In the course of the experiments it was found that leaves of most plants were not suitable for further manipulations after 5-6 days of cool storing.Cucumber and tomato leaves proved to be lasting less. Only the material from N. glauca lasts more than a month.

In exploiting a technique for mass rearing of Encarsia it is essential to adjust the climatic conditions in the glasshouse according to the following components :plant,whitefly and Encarsia.If the plant species is not exigent as is N.glauca and if the starting culture of the pest is reared separately /on cucumbers at 20-22 C/ then in the compartment for mass rearing can be maintained 25-26 C, relative humidity can be 70-80% and the photophase can be 16-18 hr with intensity 4000 Lux(Scopes,1971).These conditions facilitate mass rearing of the parasite.

For purification of the parasite population is used one peculiarity of the pest i.e. to fly off 4 to 5 days before its flight period begins.This requires however constant supply of equalized in age material which is hardly possible with the mass rearing of both species.Besides along with the leaves colonized by Encarsia, spider mites,aphids(including virophorous),thrips,larvae of Liri omyza sp.,spores from various pathogenes and saprophytes are readily introduced into the glasshouse.Thus the phytosanitary conditions in the glasshouse are deteriorated.

It is important that Encarsia formosa should be introduced in pure state removing it from the plant material in advance.Experiments showed that the smooth leaf surface which is covered with wax layer facilitates the removing of pupae and placing them on small cardboards (5 x 7 cm large) causing them no damage. Thus pupae can be distributed approximately in equal numbers on the substrate ensuring thus easy determination and control of released para sites. Most essential however is the use of special glue which kills the unparasitized whiteflies by dehydrating the nymph yet it does not check the flying off of Encarsia. Thus high purity of the parasite population is achieved, and the percentage of flown off adults is about 90-100%.

Through experiments we found out that it was expedient to rear Encarsia in high glasshouse made of steel,providing good ventilation as well as temperature,air humidity and illumination regulation.It is advisable to use more compartments though smaller,taking into account the fact that out of 1 cm^2 glasshouse area can be obtained up to 10 000-15 000 individuals of Encarsia for the needs of biological control.

1.2.DESCRIPTION

Parasite rearing starts with contaminating Nicotiana glauca (at the stage of 6-7 leaves) with whitefly and each plant is infested by 500-600 whiteflies gathered from the starting culture. Two weeks later N.glauca is populated by Encarsia,15-20 species per leaf.About 40 days later when the population has consolidated it is possible to remove the parasitized pupae and introduce them into the glasshouses.Subsequently the material of Encarsia is gathered every 15-20 days once the pupae on the corresponding level has become black.From each level of leaves are preserved 1-2 leaves containing parasitized pupae for further reproduction of Encarsia.

In glasshouses should be introduced only equalized in age material of Encarsia,i.e. purified of whiteflies,mites or their patho genic organisms.The percentage of individuals at imago stage should be at least 95%.Removal of parasitized pupae from the leaves of N. glauca can be accomplished by a mechanical system consisting of re volving cylindrical brushes set in motion by hand or mechanically. This method is suitable for small batches of the parasite when used to suppress single sources of the whitefly. With mass colonization of large batches it is advisable to accomplish it upon the natural substrate(i.e. upon leaves).Irrespective of the mode of parasite colonization (either on small cardboards or on leaves)its purification is obligatory.It can be achieved in two ways :

a)by means of glueing single pupae on small cardboards coated with glue consisting of :the white of an egg,30 gr sugar and 150 ml water.1 cm^2 should contain about 10-12 parasitized pupae so that on 4 cm^2 of the glued surface should be hold about 40 parasites(i.e. the appropriate rate).This dose is achieved by means of small card boards (2x2 cm) pasted with the above mentioned glue on which para sitized pupae are placed. The pupae that remained unglued are put on atray and used again.Every square should contain 40 parasites.

b)by means of purifying the parasitized pupae directly on the lea ves of N.glauca.This can be done by placing the collected leaves on horizontal surface pasting them with the above mentioned glue. Before introducing them in the glasshouse leaves should be cut into pieces 4-9 cm^2 large (2x2 to 2-3 cm).This method requires less manual labour and it is suitable for preparation of large batches of the parasite.

creation of an easily attainable and rapid method of testing for resistance has made possible to further reduce the number of chemical treatments, this clearing the way for the introduction of the bioagents (Natskova, 1981, 1981a). Naturally, these results are only possible with observing a number of mandatory prophylactic and organizational measures, limiting the spread of the white fly. To this end, the possibilities of the yellow sticky traps were studied as a means for limiting the migration of the insect (Natskova, 1986).

In the meantime, a technology for the mass production of Encarsia formosa was developed (Natskova, 1984), this being easily accessible and demanding small investments. This created an actual prerequisite for the broad introduction of an open form of integrated control including the effective use of bioagents.

1.2 Description

The integrated control of T.vaporariorum on tomatoes is based on a combination of inter-related and supplementing each other measures following a chronological order. Thus, the technology of the control is determined by the nature and the method of growing the crop and the state of the pest population. Fundamentally, two basic schemes of control, aimed at protecting the plants of the winter planting or of autumn or year-round growing exist in this country.

The organizational and prophylactic measures have to be conducted irrespective of the crop and the method of itsgrowing. This guarantees optimal conditions for conducting the control, thus limiting to the greatest possible extent the sources of the greenhouse white fly reproduction.

The placing of yellow sticky traps under the ventilation openings and around the doors to prevent the white fly from entering into the greenhouse is done initially, prior to the planting, resp., to the emerging of the seedlings. The winter planting of the tomatoes has to be concluded before the outer air temperatures have reached a maximum of 8 to 10 degrees C at daytime.

With the conducting of all prophylactic measures and with winter planting of the tomatoes, the protection of the plants is achieved at an unusually low density of the pests, this being an unconditional necessity for an effective application of the encarsia. The necessity of control measures is determined by the concrete conditions and the control operations are conducted in the following order:

Single white flies,discovered at planting time,are treated with a system preparation. No treatment is needed if there is not a single white fly present in the greenhouse and the seedlings are absolutely healthy. After discovering single white flies on separate places and the daytime maximum temperatures of the air inside the greenhouse are above 16 to 18 degrees C, the resettlement of the encarsia is conducted near to the places of origin of the white flies, at a distance of 20 m from them. The resettlement of the encarsia at maximum temperatures below 18 degrees C is to be avoided, because the parasite is ineffective under such conditions. When the greenhouse is heavily infested by white flies, a colonization of 4000 to 5000 parasites per dekar is undertaken, in groups of 40 to 50 parasites and at intervals of 10 plants. In both cases, the colonization is done at 15-day intervals for 4 or 5 times until there is no more than one fly per plant. In case the pest is at a density of over one fly per plant, the crop is treatedwith a preparation having a short duration effect. After reducing the pest population, the introduction of encarsia continues at the norms shown above. In the opposite case, chemical control is undertaken.

The all-year round growing of tomatoes proceeds normally in the presence of a high density of the white fly. This limits the possibility of applying the encarsia. Due to this, the basic method left over is the chemical control, founded on the thresholds of economical harmfulness. All efforts are directed during the preharvesting period towards reducing to a minimum the density of the pests, so that at time of harvesting of the fruits the use of chemicals be sharply limited. It is expedient to use preparations with a long-duration effect during the first period. These lead to a break in the development cycle of the pests. Such chemicals are the system preparations and others designed for spraying. The harvesting having begun, chemicals with a low toxic effect and short duration on warm-blooded creatures are used.

The thresholds of harmfulness change according to the size of the plants. Spraying the tomatoes during the autumn-winter season is conducted when 20 white flies per plant are detected and at the end of March - 10 to 15 white flies per plant. Spraying the fruit-bearing tomatoes during the autumn-winter period is done by a density of 40, and during the spring-summer season by a density of 25 to 30 white flies per plant. The choise of chemicals is done after testing for resistance.

The addition of ovicidic means is obligatory in case of determining a great number of eggs in the population.After the establishment of a stable structure phase of the pest population, the control of which is especially difficult, the treatments are undertaken more frequently with the preparations used one after the other or in combinations, so as to destroy to the greatest possible extent the population of the pest. The frequently undertaken treatments continue until all the larvae are destroyed. With a low density of the white fly, suitable temperatures and limited sources of infection, the encarsia may possibly be applied even with the all-year round or autumn growing of tomatoes. However, in the case of this country's conditions, this is quite difficult.

The system developed and introducedin the integrated control of the greenhouse white fly brought to a reduction in the use of chemical preparations by 80 to 83 per cent. This resulted to a sharp decrease in costs for chemicals, to an improvement in the quality of the production and the phytosanitary condition of the greenhouses. The system is adopted by all tomato growing greenhouses in this country. An instruction elaborated for this purpose, is approved in December 1985 by the Bulgarian Ministry of Agriculture.

With a view to improving the white fly control, the investigations aimed at optimizing the quality of spraying still continue accompanied by endeavours to elucidate the effectivity of the microbial means and the place they claim to occupy in the integrated system of tomato production. The possibilities of combining the chemical control with the useful activity of the bioagents are also studied.

The future investigations will be directed towards elaborating an integrated system of control of thebasic greenhouse crops pests.

For discussions I suggest the following themes:

1. Perspectives of the microbial means of the white fly control, due to the fact that the entomophagae are very sensitive towards the environmental conditions, while their production is very labour-consuming and their application is not always successful.
2. Determining the density ofT.vaporariorum.

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BIOLOGICAL CONTROL OF **LIRIOMYZA BRYONIAE** ON TOMATO BY **CYRTOGASTER VULGARIS** AND **DIGLYPHUS ISAEA**

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Summary

The biocontrol capacity of two parasitoids on the tomato leafminer, **Liriomyza bryoniae** (Kalt.) (Diptera: Agromyzidae), was compared in greenhouse chambers. The parasitoids studied were the pupal ectoparasite **Cyrtogaster vulgaris** Walker (Hymenoptera: Pteromalidae) and the larval ectoparasite **Diglyphus isaea** (Walker) (Hymenoptera: Eulophidae). **C. vulgaris** did not become established when released as newly emerged adults. When hibernating females or experienced females from a laboratory rearing were used, parasitism occurred but was too low to control the growth of the leafminer population. **D. isaea,** released as newly emerged adults, effectively suppressed leafminer population.

Introduction

Several species of parasitic Hymenoptera are natural enemies of the tomato leafminer **Liriomyza bryoniae** (Kalt.). Swedish growers of greenhouse vegetables can buy two species from the Netherlands, the braconid **Dacnusa sibirica** Telenga and the eulophid **Diglyphus isaea** (Walker). Both are also members of the Swedish fauna and often immigrate into greenhouses during summer (Nedstam 1980). Practical experience in Sweden has shown that **D. sibirica** is a good biocontrol agent against **L. bryoniae** in cucumber, but it has only been successful in tomato when combined with **D. isaea** (introduced or immigrating in from outdoors). The latter always became the dominating species within a couple of months in the cases studied (Nedstam, unpubl.). This finding corresponds with reports from other Europan countries on natural biological control of a leafminers by **D. isaea** (Hendrikse et al. 1980, Wardlow 1984, Calabretta and Nucifora 1985). In the Netherlands **D. isaea** often invades greenhouses as early as in May/June (Minkenberg and van Lenteren 1986), but in Sweden invasion cannot be expected until July. In France **D. isaea** has been mass-reared and used against **L. trifolii** (Burgess) with good results (Lyon, pers. comm.)

As the price of **D. isaea** has been high in Sweden (about US$ 200 per 1000 in 1986) very few tomato growers have bought this biocontrol agent. To find a cheaper alternative, work has been going on with another parasitoid on leafminers (and other flies), **Cyrtogaster vulgaris** Walker (Hymenoptera: Pteromalidae), which can be reared at low cost on **Drosophila melanogaster** Meigen (Diptera: Drosophilidae).

The development of **C. vulgaris** at different temperatures was compared with that of **L. bryoniae** and D. **sibirica** (Nedstam 1985). **C. vulgaris** developed at the same rate as **L. bryoniae** but more slowly than **D. sibirica** at all temperatures. Still **C. vulgaris** has a high fecundity (Lindhagen, prel. results), thus it was regarded as an interesting species for further studies.

This report covers two experiments in greenhouse chambers with **C. vulgaris** and D. **isaea** against **L. bryoniae** on tomato.

Methods

General: Six identical greenhouse chambers (6x3 m^2) were used in the experiments. Night temperatures were kept at +17° C in 1985 and at +19° C in 1986. In each chamber 22 insect-free tomato plants of the variety "Ida" were planted on plastic-covered rockwool mats during week 8. **L. bryoniae** was introduced a few days later as 10 newly emerged pairs per chamber. Once the infestations were established, the parasitoids were introduced. The leafminer populations were followed during 3 generations by making weekly counts of puparia in trays (10 per chamber, size 160 cm^2) placed under the plants. A counting apparatus for seeds was used when numbers exceeded 100 puparia per tray. Parasitism by **C. vulgaris** was studied by sampling each pupal generation of the leafminer separately. Activity of **D. isaea** (parasitism + host feeding) was estimated from counts of dead and living leafminer larvae in leaf samples.

1985: **L. bryoniae** was introduced on Feb. 19 (week 8) into all six chambers. Once pupation had commenced, **C. vulgaris** was introduced (March 4, week 10). Ten pairs of parasitoids, newly emerged from **L. bryoniae** and which had not fed or mated previously, were placed in each of three chambers (introduction rate: 1.1 per m^2). However, a sampling of puparia in March showed no trace of parasitism whatsoever, even though 200 puparia per chamber were examined. The decision was then taken to start anew with hibernating females collected outdoors, since I knew from past experience that these would start ovipositing as soon as they were brought into lab or greenhouse conditions and encoutered fly puparia. This time **D. isaea** was included as a comparison. Thus 100 pairs of **D. isaea** (newly emerged from year-around rearing on **L. bryoniae)** and 100 females of **C. vulgaris** were introduced into each of two chambers during week 13 and 14 respectively. It was considered necessary to use high numbers of parasitoids at this time, since at least a 10-fold increase of leafminers was expected in the second generation. Two chambers with leafminers only were kept as controls.

1986: In this experiment I wanted to improve the conditions for parasitism by **C. vulgaris,** while **D. isaea** was introduced in the same way as in 1985 but at a density of only 10 pairs per chamber (1.1 per m^2). **L. bryoniae** was introduced on Feb. 28 (week 9). On March 10 **D. isaea** was introduced as newly emerged adults into two chambers. The following procedure was used when starting the two chambers with **C. vulgaris:** Hibernating females were collected outdoors in January and offered pupae of **L. bryoniae** for oviposition. The sex ratio of the progeny was estimated. Adults of both sexes were allowed to feed on honey solution for 6-8 h after emergence and before mating. Two males were placed with each female in a glass vial together with a few puparia of **L. bryoniae.** After mating and when the females had started to show interest in the puparia (examining and stinging), they were transferred into the greenhouse chambers together with one male each.
Fifty pairs per chamber were introduced on March 14 (5.5 per m^2).

Results and discussion

1985: The first leafminer generation was evenly distributed among the six chambers. During the first 4 weeks, 38.7±8.5 puparia were collected per chamber (10 trays). The fact that no establishment of **C. vulgaris** took place subsequent to the first introduction cannot be explained by bad timing since pupation had started the day before introduction. Other factors must have been involved, e.g. disrupted searching behaviour or too little food available to reach sexual maturity. When hibernating females were used later on, some establishment occurred, but it was much too low to have any influence on the leafminer attack. On the other hand D. **isaea** established itself rapidly and had a dramatic effect on the leafminer population.

Fig. 1 shows the number of leafminer puparia collected per chamber through three generations (mean values from two chambers per treatment). By week 22 **D. isaea** had spread to all other chambers as well, which explains the low counts in week 23, when the fourth generation should have started reaching its maximum. The experiment was then terminated. Accumulated numbers of puparia during weeks 18-22, representing the third (and part of the fourth) generation are given in Table 1, and percentage parasitism throughout the period is presented in Table 2.

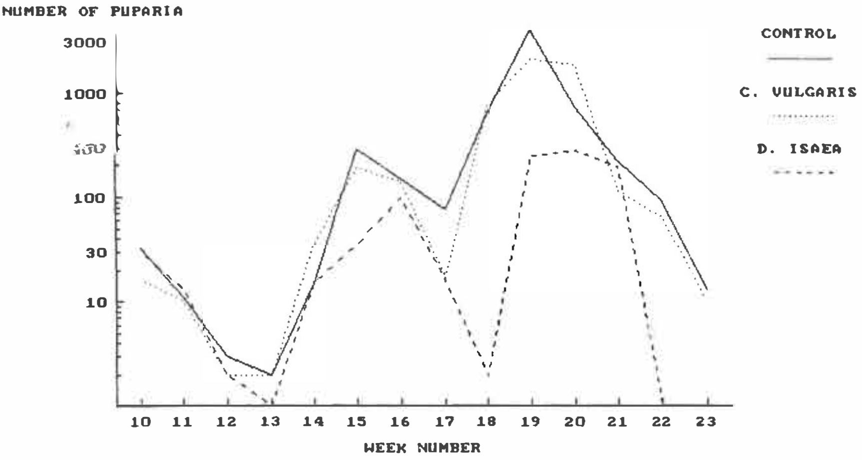

Fig. 1. Effect of **C. vulgaris** and D. **isaea** on **L. bryoniae**, 1985.

Table 1. Leafminer puparia in the third generation, 1985.

Treatment	**No. per chamber (10 trays)**	**Relative numbers**
Control	5526 ± 758	100
C. vulgaris	5269 ± 1104	95
D. isaea	726 ± 4	13

Table 2. Per cent parasitism on **L. bryoniae**, 1985.

		WEEK NO		
	16	19	20	23
C. vulgaris	4.7	6.1	N.R.	10.2
D. isaea	5.4	N.R.	41.7	97.3

1986: The first leafminer generation was less evenly distributed than during 1985 with relatively few larvae in the control chambers. During the first 3 weeks of pupation 61.3±41.1 puparia per chamber were collected in the trays. The suppressing effect of **D. isaea** was again very good, as can be seen in Fig. 2. The experiment was discontinued in week 20, since by then **D. isaea** was moving into all other chambers.

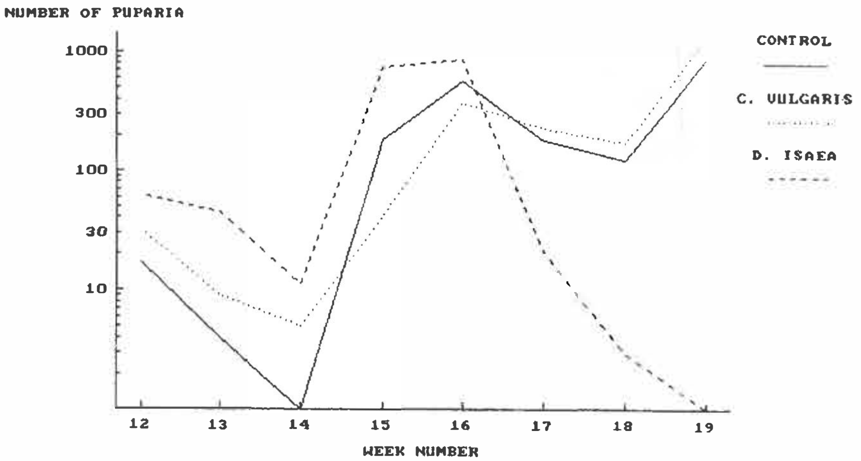

Fig. 2. Effect of **C. vulgaris** and D. **isaea** on **L. bryoniae**, 1986.

At first, **C. vulgaris** looked promising, since the mated and experienced females were quite active after introduction, causing close to 50 % parasitism in the first pupal generation of the leafminer (Table 3). But in the long run **C. vulgaris** could not keep up with the leafminer development, and when parasitism eventually fell below 20 %, **C. vulgaris** became ineffective at controlling the leafminer population.

Table 3. Parasitism by **C. vulgaris** on **L. bryoniae**, 1986.

	Leafminer generation					
	I	(n)	II	(n)	III	(n)
% parasitized pupae	45.1±1.2	93	12.1±5.3	576	16.9±2.5	1292

During 1986 the sex ratio of **C. vulgaris** progeny was also studied, both from hibernating females and in the subsequent generations in the chambers (Table 4).

Table 4. Sex ratio in **C. vulgaris**, 1986.

	Progeny from hibernating females	(n)	Emerging from leafminer generation I	(n)	II	(n)	III	(n)
♀♀ : ♂♂	1:1.1	183	1:1.2	42	1:4.3	69	1:6.2	210

The results indicate disturbed mating, which might have been caused by the rather unnatural greenhouse environment with glass, concrete and plastic and a total lack of nectar-producing plants or other food sources for the males. The females often host-feed, so they are better equipped for life in a tomato producing area, but they do not produce daughters when unmated (Nedstam, unpubl. results). The skewed sex ratio could partly explain the poor performance of **C. vulgaris** in this experiment.

General discussion: The fact that **D. isaea** gave effective and rapid control of the tomato leafminer while **C.vulgaris** failed is reflected in the practical greenhouse situation in Sweden. In commercial tomato production **D. isea** often exerts spontaneous biocontrol while **C. vulgaris** only has been found occasionally and never as the dominating species. Part of the explanation for this could be that the rate of development of **D. isaea** is higher than that of **L. bryoniae** (Minkenberg and van Lenteren 1987) while **C. vulgaris** has almost the same rate as **L. bryoniae** (Nedstam 1985). Other factors, such us searching behaviour or mating problems might also be of importance.
The experiments described here show that **C. vulgaris** is not successful even when well-fed and experienced females are introduced at high densities ($5.5/m^2$). Thus this species is of little interest for further studies of applied biocontrol. **D. isaea** will, of course, continue to be of high interest, especially if a low-cost production, as outlined by Parrella et al. (1987) for **D. intermedius**, could be started in Sweden. Another alternative would be to buy the less expensive **Dacnusa sibirica** from the Netherlands and combine it with a small-scale, early introduction of **D. isaea.** An evaluation of this system in commercial greenhouses has started and will continue in 1987.

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MOVEMENT OF ADULT GREENHOUSE WHITEFLIES, TRIALEURODES VAPORARIORUM, AND ITS RELEVANCE FOR THE DEVELOPMENT OF SPATIAL DISTRIBUTION PATTERNS

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Summary

In this paper we describe our approach to developing a simulation model for the movement of Trialeurodes vaporariorum within and between plants in a greenhouse. Eventually, this model should be incorporated into a population-dynamical model, to obtain a general model for predicting numbers of whiteflies in time and space.

1. Introduction

The greenhouse whitefly, Trialeurodes vaporariorum (Westwood) (Homoptera, Aleyrodidae) is currently being controlled by seasonal inoculative releases of the parasite Encarsia formosa Gahan (Hymenoptera, Aphelinidae) on 1700 ha of greenhouse crops in different countries. In order to optimize the timing, numbers and location of parasite releases for different greenhouse situations, we are studying the possibility of predicting the numbers of whiteflies in a greenhouse in time and space by developing a simulation model.

For making such a (predictive) model, information on two main aspects of the whitefly's ecology are needed:

- population dynamics: how do numbers of whiteflies increase in time and which factors influence population growth?
- spatial distribution: how do whiteflies distribute themselves over the plants, how are spatial patterns generated in time, and what are the factors affecting these processes?

If one wants to understand the processes that govern the growth of a single group (clump) of whiteflies and that lead to a certain spatial distribution pattern, one has to study the insects at the individual level. For this purpose, it is convenient to divide the life cycle of T. vaporariorum - which can in this context be regarded as the cyclic process of the dynamics of numbers in space and time - into three phases. This (arbitrary) division is given below, together with reference to the information available at the time of the previous I.O.B.C. meeting in Darmstadt, 1983.

1. Feeding and oviposition by adults. Adult whiteflies aggregate on the underside of the uppermost leaves of their host plants, where they feed and lay their eggs. Longevity, fecundity and oviposition frequency of the adults and the total number of eggs deposited on the leaves of different host plants have been studied by Van Boxtel et al. (1978), Van Sas et al. (1978) and Verschoor - van der Poel and Van Lenteren (1978).
2. Development of immature stages. Because immature whiteflies are sessile, the combination of oviposition restricted to one area and plant growth leads to a typical vertical distribution of the different developmental stages within the plant. Emergence of adults takes place in the lower part of the plant. For a survey of the factors influencing the rate of development and the survival of

immature stages, we refer to Van de Merendonk and Van Lenteren (1978).
3. Movement of adults. The third phase consists of movement of adults from the place of emergence on the lower part of plants to the feeding and oviposition sites on the upper leaves. This movement has two components: vertical movement within the plants, leading to aggregation of adults in the top of the plants, and horizontal movement towards neighbouring plants, leading to an increase of the area occupied by a clump.

Results concerning aspects 1 and 2 have been combined into a state-variable model, which predicts the population growth of T. vaporariorum in an excellent way (Hulspas-Jordaan and Van Lenteren, 1984).

Until recently the mechanism of insect movement received little attention; especially experimental studies of individual insects were rare (Stinner et al., 1983). For the greenhouse whitefly hardly any information was available in this respect. Therefore, we decided to fill up this gap and started a research project in 1984, as a cooperative effort of the Agricultutal University, Wageningen (the Netherlands) and Beijing Normal University, Beijing (People's Republic of China). In China, information on population dynamics, spatial distribution and optimized control of T. vaporariorum is also badly needed as this insect is becoming a major pest in the northern provinces of the country.

2. Steps in our research

a. Obtaining biological data on adult whitefly movement through observations of individual insects.

Separate experiments were conducted for the study of within-plant (vertical) and between-plant (horizontal) movement. A number of adult whiteflies were followed at 1- or 2-hour intervals (in the first or second experiment, respectively) from the moment of emergence until the moment of settling down. No emergence and hardly any movement occurred during the night. During the day, a distinct correlation exists between the temperature and the rate of movement. This confirms earlier observations by Lloyd (1922) and Weber (1931).

Most insects emerged in the early morning on leaves 7-9 (counted from the top). After about 8 LH (Light Hours, i.e. the number of hours spent between 7 and 21 h) the adults left the leaflet on which they had emerged. The actual upward movement started at an age of about 9 LH, when they departed from the leaf of emergence. Then the insects continued moving upwards until having reached a preferred leaf, in this case at an age of 40 LH (i.e. towards the end of the third day after emergence), after which the average position stabilized at 2.5 leaves from the top of the plant (fig. 1a,b). The majority of the insects left the plant of emergence within a few days. After 50 LH only 7 % of the animals was still present on the plant of emergence (Noldus et al., 1985).

In the second experiment, between-plant movement started after ca. 6 LH. At an age of 10 LH, an average speed of 3.5 cm/LH was reached and after 40 LH the net dispersal ceased at a density of circa 4 animals/plant and at an average distance of 125 cm from the plant of emergence (fig. 1c) (Noldus et al., 1986a).

b. Study of possible mechanisms causing the observed movement through manipulative experiments.

Among the factors that most likely determine the extent and rate of whitefly movement are leaf quality, whitefly density, and abiotic factors like temperature.

Special experiments were carried out to investigate which stimuli play a role in feeding-site selection by whiteflies. We found that T. vaporariorum does not distinguish between leaves of different ages from a distance. Selection occurs after landing and a strong preference for young leaves is shown. Transferring a whitefly from a young leaf to an old leaf or vice versa leads to significant changes in behaviour: on the young leaf more time is spent probing (including feeding) and less time walking. Rejection of an old leaf occurs sooner if an insect has previous experience on a young leaf: inexperienced females depart from the leaf after on average 6 probes of 3 min each; experienced females leave on average after 3 probes of 2 min each. Young leaves have a higher content of soluble as well as protein nitrogen, compared with old leaves, so the preference may have adaptive value (Noldus et al., 1986b).

These results correspond with earlier findings by Verschoor-van der Poel and Van Lenteren (1978) in experiments on selection between host plants of different species. They also showed that selection by T. vaporariorum did not occur from a distance but after landing on a plant.

The effects of varying whitefly densities and temperature on the rate of dispersal were studied by Van Vianen et al. (in prep.). Within the range of densities tested, they found no influence of the initial number of whiteflies present on the central leaf from which dispersal took place. However, higher temperatures caused significantly higher rates of dispersal.

c. Study of spatial distribution patterns in greenhouse conditions through numerical analysis of existing data.

A comparison of data from various authors led to the following generalizations. In small greenhouses, frequencies of numbers of whiteflies per plant mostly fit to the negative binomial distribution (Xu et al., 1980, 1981; Yano, 1983; Yano

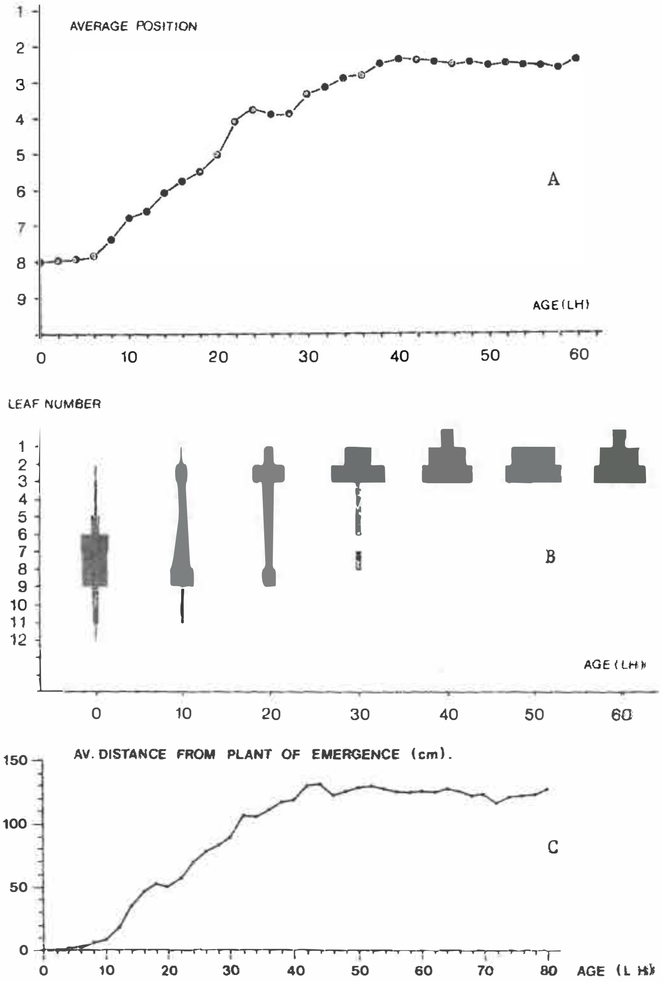

Figure 1
a. Average vertical position of whiteflies within plants with proceeding age.
b. Vertical distribution within plants of a population of whiteflies with proceeding age.
c. Average net distance moved per individual in a population of whiteflies with proceeding age.

and Koshihara, 1984). In large greenhouses, however, distributions are far more aggregated (Ekbom, 1980), sometimes to such extent that they do not fit to any commonly used distribution model (Eggenkamp-Rotteveel Mansveld et al., 1982). Apparently, different levels of spatial distribution of whiteflies can be distinguished, i.e. 'patches' of whitefly infestation which can be subdivided in smaller units of distribution, clumps (groups of whiteflies). Calculation of Iwao's (1972) ρ-index for the latter population indicated that the smallest unit of distribution comprised about one plant (Noldus et al., 1986c).

d. Construction of a simulation model for whitefly movement.

We have built simple deterministic and stochastic simulation models based on the data obtained in step a. When we use quantitative aspects of movement (numbers of insects staying on a plant, average rate of movement, number of leaves moved by an individual during a time interval), derived from the observed values (averages or frequency distributions) as input parameters, we obtain reasonably good descriptions of the behaviour of the population.

However, the goal is, of course, to use biotic (whitefly density, leaf quality, etc.) or abiotic (temperature, light, etc.) variables as input parameters in the model. Until now this has been very difficult, as not yet many quantitative data on the influence of these factors are available. This step has therefore not yet been completed (Xu et al., in prep.).

e. Incorporation of the movement model into an existing population-dynamical model.

Our goal is to obtain a general model for predicting numbers of whiteflies in time and space. This step still lies in the future, however, because our movement models have not been finished yet, and the model for population dynamics has only just been completed (Hulspas-Jordaan et al., 1984).

3. Future research

As may be clear from what has been stated above, more research is necessary on:

- The biological mechanisms and abiotic factors underlying whitefly movement. This includes the exact role of leaf quality, and ways to quantify it, as well as the role of whitefly density, and other (abiotic) factors.
- Improvement of the simulation models for movement, with the aid of more and better quantitative data on the mechanisms governing movement.
- Integration of models on horizontal movement and the knowledge on spatial distribution patterns of whiteflies.
- Integration of models on movement and population dynamics.

4. Suggestions for discussion

- Will models containing all aspects mentioned above ever be used for developing *Encarsia formosa* release strategies?
- Can sampling programs be derived from this kind of research which are useful not only for the scientist but also for the applied worker?

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THE STATE OF PROTECTED CROPS IN THE MEDITERRANEAN BASIN AND THE PRESENT POSSIBILITIES FOR A PEST INTEGRATED CONTROL

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Summary

In this study we make a point of the greenhouse crops situation in the Mediterranean area and the possibilities of integrated control in that environment are dealt with.

1.1 Introduction

Protected crops in the Mediterranean basin have been established since the sixties, between 35° and 45° degrees North latitude, mainly along the coast areas of the Mediterranean sea.They are characterized by protective accomodations with rather precarious features and which are in any case of limited duration. These structures are made of wood or of other materials and are covered with plastic films; the differentiation among accomodations is noteworthy. These protected crops in the Mediterranean area have had their first significant affirmation in Sicily (I) in the province of Ragusa since 1960 onward. Recent data point out that in the year 1984 the European and African areas of Mediterranean region have reached about 65,000 ha of surface under greenhouse, covered by plastic material, with more than 19,000 ha in Italy, 15,000 in Spain, 9,000 in France and Turkey, 3,000 in Greece and Algeria.

About 58,000 ha are assigned to vegetable crops and 7,000 to floral crops. To this surface 56,000 ha of crops growned under little tunnels or various shelters must be added, 20,000 ha of which are in France, 16,000 ha in Italy, 6,000 in Spain. As a whole the sector of Mediterranean vegetable and floral crops interests about 120,000 ha, to which other 5,000 ha, used for the protection of fruit trees (grape, banana, citrus, etc), must be added. Then this sector covers 40% of the protected crops world surface, which has been esteemed about 280,000 ha (La Malfa, 1986). We will stop our attention only on greenhouse growings in order to evaluate in them the phytosanitary problems, depending on the presence of insects, mites and nematodes and to discuss on the possible means of integrated control.

1.2 Environment and growings of Mediterranean greenhouses

A common feature of Mediterranean greenhouse growings is their site, within any of the countries (Italy, Spain, France, Portugal), mainly in the regions situated at the very south, which enjoy of a more favourable thermic and luminous course during winter.

As far as Italy is concerned a third of greenhouses is in Sicily and 90% of tomato crops are grown in unheated greenhouses where heating has been supplied today by a double covering which improves the thermic isolation of the greenhouse and avoids the disadvantages of the droppings of temperature when the external one is below the zero. In January-february the average of lowest temperatures is around 4°-3°C and only sometimes the temperature drops below the zero. In Italy in the cases of heated greenhouses (10%

about of the whole) the direct contribution of energy is on average not more than 15% of that employed in the countries of Northen-Central Europe. Thence the direct contribution of energy is void or slight.

In all the Mediterranean area of protected crops one of the feature of greenhouse crops is their interruption during the warmest months. Another real problem is the proximity of the same host plants in the field and in the greenhouses, so that in these countries an epidemiological study of pests and of their natural enemies will be carried out together indoor and outdoor. The proximity of the two systems must lead to their having an unavoidable repercussion on each other. So it happens at the beginning of winter on protected crops. During September-October, the outdoor crops have already been harvested and their pests have run out of food. Hence, in their search the pests penetrate into the greenhouses via opening windows and attack the young plants. This occurs also in Israel (Berlinger, 1986), in Spain (Gabarra I Amber, 1986) and in Italy.

In Sicily *Encarsia formosa* (Gahan), *Phytoseiulus persimilis* Athias-Henriot and *Diglyphus isaea* (Walker) are becoming established in the outdoor host plants and normally populations of these beneficials spread via open window on indoor coltivations where no insecticides are used. *E. formosa* can occur indoor at the end of summer from outdoor, developping mainly in the crops in which the level of culture is nearer to the soil and dayly water sprinkles are done, as in the gerbera transplanted in summer, in which better conditions of relative humidity and temperature are attained. Hence in one of these greenhouse crops, transplanted in July and not treated chemically, at the middle of October about 26,59% of pupae were parasitized by *E. formosa*, penetrating from outside and naturally developping (Nucifora and Vacante, 1981).

In Crete Michelakis (1982) has seen that three releases of *Encarsia* done in autumn have induced a rate of 33.3%-36.7% of parasitization in January, but from February to April parasitism ceased at all, because of low temperature levels, so that other new releases had to be done in April-May. In Sicily, during spring *Encarsia* can naturally reappear some time; if it comes out from the end of March onwards good levels of natural parasitization can take place.

Nevertheless this wasp more often arrives in May and in this case it does not bear practical effects, so that generally artificial releases are needed. The possibility, instead, that *D. isae* offers in this way is better and a naturally introduced population from this wasp can easily build up at proper time (Calabretta & Nucifora, 1985). Also in winter the activity of this wasp is acceptable, where that of *Encarsia* stops entirely.

In the unheated greenhouses of the Mediterranean basin the pests activity follows the pattern of the temperatures. Hence the whitefly population density generally declines from the end of October to December, remains at its lowest level in January-February and increases again from March to the end of the cropping season, in July. This also occurs in Israel (Berlinger, l.c.), in Greece (Michelakis, l.c.) and in Italy. In these countries and in particular condition of environment there are some times high levels of whitefly populations up to January, but it isn't a recurring situation. Instead, in some areas of Spain it is a normal condition.

The leafminer infestation takes place from Autumn onwards and in winter remains at high levels.

During late spring on the beginning of summer the presence of the two pests is so high that rather a poor success can be achieved by the use of an integrated control, without using selective insecticides, because of the presence of too many adults and larvae in a crop (Nucifora, 1985; Nucifora and Calabretta, 1985).

Nowadays in Sicily besides the whitefly, the leafminers *Liriomyza bryoniae* (Kaltenbach) and *L. trifolii* (Burgess) are two very important pests on some vegetables or flower crops. *L. trifolii* is the main pest in gerbera protected crops in Italy and it has been here the worst problem; *L. bryoniae* is almost bearable on tomato crops and less destructive.

The two spotted spider mite (*Tetranychus urticae* Koch) is spreading on vegetables, as well as on flowers and ornamentals (Vacante, 1985).

Other pests of the protected crops are mainly the caterpillars (*Spodoptera littoralis* (Boisd.)) and *Chrysodeixis chalcites* (Esp.) (Inserra and Calabretta, 1985; Nucifora and Calabretta, l.c.), aphids and the onion trips (*Thrips tabaci* Lind.). Besides the two spotted spider mite, the broad mite, *Polyphagotarsonemus latus* (Banks), can often appear on sweet pepper and gerbera (Nucifora, 1980) and the tomato russet mite *Aculops lycopersici* (Massee), on tomato crops (Vacante, 1982). In Israel the worst problem is the presence of tobacco whitefly, *Bemisia tabaci* Gennadius, which transmitts destructive virus diseases. Another problem of greenhouse crop control in the Mediterranean region is the presence of the root-knot nematodes (Calabretta and Privitera, 1985). They constitute one of the most dangerous factors of the "ground exhaustions" (Noto *et al.*, in pressing). The beneficials (*E. formosa, P. persimilis, D. isaea*) are naturally developping in many parts of the Mediterranean basin and can be used in the integrated pest management (Nucifora and Vacante, l.c.; Vacante and Firullo, 1983; Calabretta and Nucifora, l.c.; Nucifora, l.c.). Also some polyphagous predators (Miridis especially) can be positively investigated. One of them, *Nesidiocoris tenuis* (Reut.), has been recently noticed in the protected crops in Sicily (Nucifora and Calabretta, l.c.). It is a mirid with both carnivorous and phytophagous habits, primarily feeding on the stems and causing on them lesions of feeding rings. It stings and sucks secondarily larval and adult stages of whitefly, larvae of leafminers and also eggs of caterpillars. Its activity takes place in late spring until the end of Autumn. Other mirids, *Dicyphus tamanini* Won. and *Macrolophus nubilis* (H.S.) are experimented upon in Spain for using them in outdoor vegetable crops during summer against whiteflies. The vegetable growers in all Mediterranean countries are still using the most different chemical treatments. The development of researches during the last 5 years on alternative methods are reported in the paper of some learned workers in Italy such as in other countries of the Mediterranean basin (Grill, 1979; Quaglia, 1979; Pinoggi *et al.*, 1980; Nucifora *et al.*, 1982; Calabretta and Firullo, 1983; Nucifora and Calabretta, l.c.; Nucifora, l.c.).

The italian workers were studying the chromoattractive system and found that it, alone or with some selective chemical treatments, gives very good results. For the applications of this method yellow plates (20 cm diameter) have been used at a rate of 1 per 5-7 m^2. They are coated on each side with appropriate glue and hanged up between the young plants. In the opinion of Minkenberg & van Lenteren (1986) this method has not shown yet its sufficient realiability and is not commercially feasible, because of a very expensive cost, almost in the northen glasshouse area (van Lenteren, comm.pers.). This is not our opinion.

Today 80% of gerbera crops in the unheated plastic houses in Sicily are protected by yellow sticky traps and or biological natural control. The gerbera growers applied this method because they didn't have any other possibility of success against the American serpentine leafminer. The chemical treatments aggravate the problem. The biological control alone also gives good results if done by *D. isaea*, when any broad-spectrum insecticide is used. The traps are completely compatible with biological control. They trap the whitefly and leafminer adults, while their parasites (*E. formosa, D. isaea, Dacnusa sibirica* Telenga, etc.) are not attracted as long as sufficient and suitable hosts are present (Webb and Smith, 1979; van de Veire and Vacante, 1984). From this ascertainment a new alternative method integrating natural or artificial biological control has been developped against the greenhouse whitefly and leafminers. Thus van de Veire and Vacante (l.c.) are proposing a new strategy based on the use of chromoattractive and biological control together as an alternative method to biological control alone. The trapping capacity of yellow plates for whitefly is sufficiently good, so that the amount of *E.formosa* to be released can be reduced by three quarters with economical profit; this new strategy is today proposed for the heated greenhouse tomatoes and could be used in spring as well as in fall greenhouse crops.

The same integrated control method can be applied in the Mediterranean countries from March onward, but often an integration of both biological and chromoattractive system can be necessary. One or two quinomethionate treatments at 0.015-0.20%, accurately applied, help to reduce the whitefly infestation, without positive harmful effects against the chalchid wasp. Then yellow sticky traps, parasites action and some proper treatments together are today the suggested methods for an I.P.M. in the spring-summer vegetable crops of Mediterranean environment. In this programme the quinomethionate treatment acts against oidium disease, adults, eggs, and the first two stages of whitefly, and also against two spotted spider mites.

Against caterpillars the use of bran poisoned with methomyl or parathion is the only applied in Italy, where the use of Bacillus thuringiensis Berliner is not allowed. The aphids are controlled by pyrimicarb or ethiophencarb treatments.

This is the proposed scheme for an I.P.M. in the Spring-summer tomato crops of Mediterranean countries, but, till nowadays the employment of integrated control has not found the same approval than in the gerbera crops as far as vegetable crops are concerned. Why?

Which are the factors which go against a possibile generalization of their usage and which are the preliminary conditions that must be present for it? It could be the matter of our possible discussion.

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BIOLOGICAL CONTROL OF TETRANYCHUS URTICAE KOCH ON ORNAMENTAL FOLIAGE PLANTS IN FLORIDA

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Production of ornamental plants constitutes one of Florida's most important industries. In 1983, approximately 5,500 acres of floricultural crops, 2,100 acres of foliage plants, and 5000 acres of cut foliage plants were in production in Florida. Florida's production of nursery products rose from a wholesale value of 8.7 million dollars in 1949 to near 600 million in 1983. These figures do not reflect costs associated with turf and maintenance of plant materials which would boost the value of ornamental crops to an estimated value of 2.18 billion dollars annually.

The climatic advantages of Florida include a long growing season, long winter photoperiod with high light intensities and mild temperatures which are conducive to the production of quality ornamental plants year round. However, the same climatic characteristics are also conducive to high incidences of insects and diseases.

Chemical control is the primary method used to control ornamental plant pests. Therefore, a major portion of projects in pest management for these crops consists of pesticide screening for efficacy and phytotoxicity. Phytotoxicity and the loss of efficacy as a result of resistant pest populations are the major problems facing growers. In the foliage industry, we often observe plants more damaged from pesticide applications than from the arthropod pests themselves.

Research at the University of Florida Agricultural Research and Education Center in Apopka strives to solve the unique pest control problems that growers of tropical ornamental foliage plants must contend with. In Florida, plant-feeding mites are some of the most common and destructive arthropods found infesting foliage plants in Florida greenhouses, homes and interior landscape plantings. The twospotted spider mite (TSM), *Tetranychus urticae* Koch, is the major arthropod pest of tropical ornamental foliage plants and chemical applications as often as every five days are required for control. As a result of the many problems and economic consequences associated with chemical control, research on two biological control agents for TSM has been conducted on ornamentals in Europe (Gould and Light 1971; Sabelis 1981; Scopes 1985; Simmonds 1972; Stenseth 1976) and the United States (Boys and Burbutis 1972; Field and Hoy 1986; Hamlen 1978; Hamlen 1980, Hamlen and Lindquist 1981; Hamlen and Poole 1980; Lindquist 1981; Osborne et al. 1985, Osborne and Petitt 1985). These predators are *Phytoseiulus persimilis* Athias-Henriot and *P. macropilis* (Banks). Both species are quite similar in appearance and must be examined microscopically for accurate identification (Denmark and Schicha 1983).

The predatory mite, *P. persimilis* (PP), has a long history of use and has been the subject of over 150 scientific papers (Petitt and Osborne 1984). At the present, time PP is commercially available in the United States from at least 5 commercial companies. The second predator, *P. macropilis* (PM), has been the subject of only a few papers and very little is known about its biology, host range, efficacy, or sensitivity to various environmental parameters such as chemicals, temperature and humidity. Specimens of PM were first collected and described from water hyacinth in Eustis, Florida, by Banks (Denmark and Schicha 1983). This indigenous species is often found in University greenhouses and in commercial nurseries where pesticides are used infrequently. Hamlen and Lindquist (1981) demonstrated that this predator can be as effective as PP in both Florida and Ohio. However, other comparative data on the strengths and weaknesses of these two species is lacking.

Because of constraints placed on producers of ornamental plants to produce a final product that is free of insects and mites, the first commercial field trials in the southern United States with predatory mites will probably occur in stock plantings where some damage can be tolerated. These plants are usually grown for relatively long periods of time; 1 to 2 years for smaller plant types such as ivy and dieffenbachia. These "stock" plantings are grown in such a fashion that they produce very dense canopies. Dense canopies preclude thorough spray coverage with acaricides and, because most of the acaricides are not systemic, mites that are not directly contacted by the active ingredient escape control. As a result, chronic mite problems occur in these areas and are often spread to other areas of the greenhouse when cuttings are taken for propagation. Osborne (1986) developed methods for reducing the potential for spreading these infestations on cuttings by dipping them in fluvalinate (a synthetic pyrethroid). This technique caused little or no phytotoxicity to cuttings of many plant types, but it only achieved about a 90% reduction in TSM density. Predatory mites might be useful in suppressing hot spots or foci of TSM activity in stock plantings prior to the dipping of cuttings in pesticides. This could possibly enable the production of cleaner cuttings than are currently available.

In spite of positive results from current and past research, classical biological control of TSM has not been implemented on ornamental crops in more than a few greenhouses throughout Florida. The reasons are, in most cases, the same as those hindering development of biological control in greenhouses world-wide. The situation is best summarized in the paper "World situation of biological control in greenhouses, with special attention to factors limiting application" (van Lenteren et al. 1980). The most important factor for ornamentals is the perception that we are currently marketing pest-free products and that the use of biological controls will result in products that are infested, damaged and of inferior quality. However, complete reliance on chemical controls does not insure quality plants because their use often results in unsightly residues and phytotoxicity. Secondly, chemical controls are not always effective. As van Lenteren (1980) noted, "We have to be careful before completely dismissing biocontrol for such crops, because checking of heavily sprayed ornamental crops sometimes reveals still living pest insects, the number of pest insects being as high as or higher than crops treated with biocontrol".

Tauber (1977) listed the major assumptions made against the use of biological controls in the greenhouse. These assumptions can be summarized as follows:

1) Pesticides must be applied on a regular basis to obtain quality plants;
2) There is a lack of well-developed biological control programs to replace chemical control programs;
3) Greenhouse managers lack confidence that anything but strict chemical control programs can be relied upon to protect high value crops such as ornamentals which have low economic injury levels;
4) Totally damage-free and pest-free crops are essential and this requirement precludes the use of biological control;
5) Residue of beneficial arthropods would be unacceptable to the ultimate consumer;
6) Beneficial arthropods are not commercially available locally or in sufficient quantities when needed.

As stated in 6) above, a major limiting factor in the development of biological control of TSM is the quantity and quality of predatory mites available in this region of the United States: predators must be obtained by mail. There are a number of problems associated with this practice

1) Predators arrive in poor condition;
2) Predators are not available when needed;

3) Guidance and support groups are limited in the region.
4) Strains are not adapted for regional needs (climate, pesticides),
5) There are unreasonable governmental restrictions that require growers to have permits to import biological control agents, even though they already occur in the region.

Because biological control programs of arthropod pests infesting ornamental foliage plants in Florida are only in the developmental stages, There are no data to present on the number of growers utilizing or even attempting to utilize biological controls in greenhouses. Therefore, I will present a short discussion on the projects currently in progress at the Apopka Research and Education Center.

Non-disruptive Chemical Controls

Release methods and guidelines have been developed for vegetables in order to increase the probability of successfully controlling TSM with predatory mites. However, when a mite population has reached a high density, the cost and logistics of releasing adequate numbers of predatory mites can be prohibitive. In these cases, conventional chemical control must be employed to reduce the possibility of economic damage. The acaricides used in the ornamental industry often disrupt the predator-prey interaction to the extent that acaricides are needed for the remainder of the growing season. Osborne and Petitt (1984) reported the results of studies conducted to determine whether application of Safer Agro-Chem's Insecticidal Soap (IS) (Safer Agro-Chem, Inc., Jamul, CA 92035) could be utilized to reduce mite populations without significantly disrupting the interaction between the predatory mite and its prey. Similar studies will be conducted with the acaricides abamectin, clofentezine, and hexythiazox.

Modified Banker-Plant Method

A new project has been initiated to evaluate release methods for PP. One method we are investigating is a modification of the "Banker-Plant" method for Encarsia formosa Gahan. In this system, we envision using a host plant that is of little economic importance in the foliage industry on which we can feed a host specific phytophagous mite. These infested plants would then be inoculated with PP and placed in the greenhouse to serve as a foci from which the predators will disperse. Examples of potential host plant/mite systems are:

HOST PLANT	MITE
1) Oxalis, clover, crotalaria, sugarcane	*Petrobia harti* (Ewing)
2) Castor bean, citrus	*Panonychus citri* (McGregor)
3) Cassava	*Monoychellus caribbeanae* (McGregor)
4) Spruce	*Oligonychus ununguis* (Jacobi)
5) Corn, grass spp.	*Oligonychus pratensis* (Banks)
6) Various woody ornamental plants	*Oligonychus ilicis* (McGregor)

Microbial Pest Control

Another area of ongoing research involves the use of microbial agents to control various plant pests. However, major problems exist that could impede the development of microbial control programs. For example, our environment is so conducive to the development of plant pathogenic organisms that many growers must apply fungicides on a weekly basis. One of the most disruptive fungicides used on a regular basis in this industry is benomyl. Therefore, we are currently evaluating a benomyl-resistant (tolerant) strain of *Verticillium lecanii* (Zimm.) for the control of aphids.

Other pathogens being evaluated are *Bacillus thuringiensis* var. *israelensis*, *Beauveria bassiana*, *Hirsutella thompsonii*, *Neozygites* sp., and *Paecilomyces fumosoroseus*.

Biological Control of Citrus Mealybug

Finally, *Leptomastix dactylopii* Howard and *Leptomastidea abnormis* (Girault) are being evaluated for the control of the citrus mealybug, *Planococcus citri* (Risso). This mealybug is the most difficult to control insect pest of foliage plants. Few chemicals are effective for their control and those that are cause phytotoxicity or will be disruptive to biological control programs for mites.

In addition it should be pointed out that Florida has a rich diversity of beneficial organisms. Muma and Denmark (1970) listed 86 species of Phytoseiidae found in the state. Their publication contains keys, sections for each genus and species on diagnosis, habitat, biology, and a map indicating the distribution of each species throughout the state. When available, information is presented on what each species feeds upon. Unfortunately, very little information is available on many of the species. Because Florida's climate is quite similar to that of a greenhouse during much of the year, and because there is such a rich diversity of beneficial organisms in the state (Muma and Denmark 1970, Muma et al. 1962a,1962b), many useful beneficials may be found that could be adapted to the greenhouse environment and therefore prove useful for crop protection in greenhouses. This presents a unique opportunity for scientists in Florida to cooperate with scientists throughout the rest of the world in the development of viable biological pest control programs in protected cultivation.

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BIOLOGICAL CONTROL OF LIRIOMYZA TRIFOLII ON GLASSHOUSE CHRYSANTHEMUMS

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Summary

A method has been developed which enables the production of the leafminer parasite, *Diglyphus intermedius* (Hymenoptera: Eulophidae), at a reasonable cost. Chrysanthemum plants are exposed to *Liriomyza trifolii* (Diptera: Agromyzidae) colonies for <2 h to standardize larval development. When larvae are late second/early third instars they are exposed to colonies of *D. intermedius* for 24 h. Leafminer larvae surviving this exposure are recovered and parasites are allowed to complete development in these plants on glasshouse benches. Just prior to parasite emergence plants are cut at the soil line and placed in glass-topped sleeve cages. Emergent parasites are aspirated off the glass; they are counted and a subset is sexed at this time. Utilizing this method, a chrysanthemum plant with 350 cm^2 of leaf area produced 100 *D. intermedius* adults; approximately 30-50% of these were females. During the months of July, August, and September, 140,000 *D. intermedius* were reared and field released at a cost of $20.00 (U.S.) per 1,000 parasites. Releases of these parasites into commercial chrysanthemum ranges resulted in successful biological control of *L. trifolii*; no leafminer sprays were required for the first 12 weeks of the crop.

1.1 Introduction

Chrysanthemum production in the United States (cut flowers and pots) encompassed ca. 800 ha of growing area in 1985. These crops are valued at more than $250,000 and $500,000/ha for cut and pot chrysanthemums, respectively. This high crop value, together with the fact that chrysanthemums are grown for their aesthetic value, has made insecticides the major choice for pest control by growers. Historically, insecticides have been relatively safe to use, effective, and inexpensive. This, coupled with grower 'piece of mind' after pesticide application on such a high value crop, has made growers reluctant to try alternatives to chemicals. Furthermore, research and extension in the United States have done little to change this chemical dependency.

Some dramatic changes have occurred over the past five years that have forced growers to consider alternatives to pesticides for control of the leafminer, *Liriomyza trifolii* (Diptera: Agromyzidae). Insecticide resistance in the leafminer has rendered most registered chemicals useless. Promising new insecticides for leafminer control have encountered registration problems; thus, growers have been forced to use more frequent applications at greater rates. Insecticides are no longer effective and inexpensive. Furthermore, safety considerations are rapidly becoming a primary concern, with stricter regulations in regard to worker safety, ground water contamination, etc. at both federal and state levels. These factors have caused several state flower-growing associations in California to request seminars on biological control. This has come at a time when there is more information than ever before from research and extension on IPM/BC (integrated pest management/ biological control) for ornamental crops.

1.2 Development of Research

Research over the past 5 years on the development of IPM/BC for chrysanthemums has focused on *L. trifolii* in the areas of monitoring/sampling (Parrella and Jones 1985, Jones and Parrella 1986), insecticide resistance (Keil et al. 1985), biology/ecology (Parrella et al. 1983, Bethke and Parrella 1985, Jones and Parrella 1986), and parasitoid biology and evaluation of field releases (Christie and Parrella 1986, Jones et al. 1986, Parrella et al. 1986).

From these and other studies, we concluded that *Diglyphus intermedius* (Hymenoptera: Eulophidae) had the best potential as a BC agent of *L. trifolii* on chrysanthemums. Consequently, subsequent efforts focused on this parasite species. No commercial insectary in North America raises *D. intermedius*; growers interested in purchasing these would have difficulty obtaining them. Therefore, we developed a mass-rearing program for this parasite that could be adopted by a commercial insectary. Also, field evaluations of *D. intermedius* for BC of *L. trifolii* on chrysanthemums were conducted in order to establish the feasibility of using this parasite in an IPM/BC program for glasshouse chrysanthemums.

1.3 Mass Rearing of *Diglyphus intermedius*

Chrysanthemum plants (cultivar Hurricane) are received as rooted cuttings and planted in 2.4-cm-diameter pots (4 plants/pot). These are allowed to grow for 1 month, after which time there is approximately 350 cm^2 of leaf area/pot. Nine pots are exposed to adult leafminers for 2 h, after which they are removed and placed on glasshouse benches. A model developed to estimate the number of flies/cage at any given time estimated ca. 2,000 flies/cage. Leafminers are allowed to develop until they reach the the late second/early third instar, at which time they are exposed to adult *D. intermedius* in small cages for 24 h. We estimated that there were ca. 1,000 parasites/cage. After exposure, plants are tipped over sand-filled trays which collect any larvae surviving exposure to the parasites. Pots are then placed on glasshouse benches to allow parasite development. Just prior to parasite emergence from leaves, plants are cut at the soil line and placed in glass-topped sleeve cages. Parasites are aspirated from these cages, counted, and a subsample sexed. After initial establishment of rearing facilities, *D. intermedius* can be reared using the method outlined for ca. $20.00/1,000 parasites. Sex ratio ranges between 30-50% females. The largest recurring costs of rearing include the chrysanthemum plants and labor associated with aspirating adult parasites.

1.4 Field-Releases of *D. intermedius*

A 0.11 ha range of chrysanthemums, heavily infested with *L. trifolii*, was chosen as a release site. Immediately after the crop was planted, 5,000 *D. intermedius* were released 2 times/week for 12 weeks. No leafminer sprays were made during this time. After week 12, sprays were made for aphids and thrips which disrupted BC with *D. intermedius*. Biological control of *L. trifolii* was obtained and the crop produced was equivalent to an adjacent planting which received regular chemical treatments for leafminer control.

1.5 Future Research

More information is needed on the biology/ecology of *D. intermedius* as it relates to the leafminer, chrysanthemum plant, and glasshouse environment. A large data gap exists which would permit an accurate prediction of the number of parasites to be released based on leafminer density in the glasshouse. The compatibility of *D. intermedius* with commonly used glasshouse pesticides, especially those used for aphids, whiteflies, and thrips, is urgently needed.

The potential of using *D. intermedius* for BC of *L. trifolii* attacking other floriculture crops (e.g., marigolds grown for seed and gerbera grown for cut flowers) is needed.

1.6 Discussion

Biological control in ornamentals is generally considered to be impractical because of the low level of pests and their damage that can be tolerated. In addition, the regular applications of broad spectrum chemicals to these crops would seem incompatible with biological control (van Lenteren et al. 1980). However, we believe that BC is possible on these crops, provided: (1) a window of nonmarketability can be determined for the crop, and (2) regular samples are taken to ascertain parasite impact. The availability of a chemical that is capable of providing immediate control, should it be decided that BC is not working, would offer an incentive for more growers to try BC. The window of nonmarketability with chrysanthemums is the first 4-6 weeks of crop growth; leaf samples and yellow sticky cards are examined twice/week to monitor larval and adult populations, respectively. The material Avid® (abamectin), a good leafminer insecticide which has almost a full U.S. registration, is a chemical which could effectively control *L. trifolii* on chrysanthemums if BC doesn't work. Similar BC programs could be outlined for leafminers attacking gerbera and gypsophila grown for cut flowers and ageratum, marigolds, zinnia, dahlia, etc. grown for seed. In addition, other pests on other ornamentals may also be suitable for BC, given the criteria outlined previously (e.g., mites on roses, carnations, and gerbera).

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INDUCED DIAPAUSE FOR A LONG TERM STORAGE OF APHIDIUS MATRICARIAE

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Summary

The cold storage of aphid parasites being inside mummified aphid has a great economic importance in relation to application of IPM or BC programmes. The storage of parasites can be more successful in diapausing stage than in hibernal quiescence. Any cooperation or idea will be highly appreciated in research to induce and break off diapause of aphid parasites and other aphid enemies.

1.1 Introduction

Among the aphid parasites Aphidius matricariae seems to be effectiv in controlling aphids under glasshouse conditions in Hungary. In this connection the use of different parasites against aphid pests under glass poses well known promlems: mass-rearing, timing of mass-release, side effect of pesticides and cold storage of the parasites. There is obvious that storage of parasites has a practical importance in biological control (BC). It is a simple method to keep them alive when they are of no use. In this way they may also be easily shiped and the cost of mass production of parasites may be lowered because it will be possible in a cheaper operating period of glasshouses. Furthermore the synchronization of parasite emergence is facilited by storage.

The idea of cold storage of aphid parasites have come up for a long time. Numerous observations of various authors (Stary, 1970 a; Hofsvang and Hagvar, 1977; Shalaby and Rabasse, 1979; Polgár, 1986) are of the same opinion, i.e. well timed (parasite is last instar or prepupa stage inside mummie) cold effect stops the development of parasites. The mummies treated such a way can storage at low temperature for one or two month (only) without reducing of adult emergence dramaticaly. According to Stary (1970 b) the hibernal quiescence (HQ) is probably the most common case of arrested development in aphidiids, being most typical for the survival of a cold winter period.

1.2 Problems

In the trials of authors mentioned before the parasites were stored in hibernal quiescence (HQ). Namely, according to observation of Hofsvang and Hagvar (1979) as well as ours when the parasites were brought to an optimal temperature at which they development started than adults have emerged under normal development time. The aphid parasite Ephedrus cerasicola managed to storage in this way, i.e. in HQ for 2-2,5 monts. The successful storage of Aphidius matricariae took place in HQ for one month only (Polgár, 1986). Both species were stored at 0C° temperature. However, Shalaby and Rabasse (1979) found diapausing and dead larvae as well in the closed mummies had passed a precooling period before storage.

In my opinion an induced diapause may be a better way for a long time storage of Aphidius matricariae because aphid mummies were being in hibernal quiescence we could to storage successfully for one month only. My aim is that to find out the conditions of inducing and breaking off diapause for Aphidius matricariae.

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appendix

Country: Hungary (Under greenhouse conditions)

pests	crop protection program		
	as applied	experimental phase	research phase
Trialeuroides vaporariorum	Encarsia formosa		
Spider mites		Phytoseiulus persimilis	
Aphids		Aphidius matricariae	Aphelinas asichys Aphidoletes aphidimyza

BIOLOGICAL CONTROL OF GLASSHOUSE CROP PESTS IN THE SOUTH OF THE USSR

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The majority of glasshouses are situated in the southern part of the USSR, which allows harvests with low energy expenditure. Glasshouses (1-3 hectare each) are united into complexes with a total area from 6 to 100 ha. As a rule there are two growth cycles in glasshouses - a main and additional ones. The main one lasts from December to June, the additional from August to December. The first cycle is of major importance providing 80-85% of the total yield. Climatic peculiarities (mild and short winter) promote intensive development of pests in the open field. Their immigration into glasshouses lasts for a long time creating a difficult entomological situation.

The main pests of glasshouse crops (cucumber, tomato, sweet pepper, rose) are the glasshouse whitefly (*Trialeurodes vaporariorum* (Westw.)), the spider mite (*Tetranychus urticae* Koch.), the melon aphid (*Aphis gossypii* Glov.), the green peach aphid (*Myzus persicae* Sulz.), the rose *aphid (Macrosiphum rosae* L.) and the tobacco thrips (*Thrips tabaci* Lind.). The leafminer *Liriomyza trifolii* Burgess has not yet penetrated into greenhouses. The glasshouse whitefly is the most dangerous pest. That is why protection effectiveness in some crops mainly depends on the results of this pest control. The following entomo- and acariphages are used in practice or are in the stage of field testing: *Encarsia formosa* Gahan against the glasshouse whitefly on cucumber, tomato and sweet pepper; *Phytoseiulus persimilis* A.-H. against the spider mite on cucumber, tomato, pepper and rose; the predaceous gall midge, *Aphidoletes aphidimyza* Rond. against rose and green peach aphids on rose; *Aphidius matricariae* Hal. against the green peach aphid on pepper; *Amblyseius mckenziei* Sch & Pr. against the tobacco thrips on cucumber and pepper. The work on melon aphid control is in stage of testing.

Cucumber.

Glasshouse whitefly. The effectiveness of *Encarsia* on cucumber greatly depends on pest density and release time. Timely application of the parasite (10 individuals/m^2) in 3-4 replicates with 10-14 days intervals at the whitefly density 1 adult/m^2 allows to control pest multiplication during 7 months and to provide harvest protection. If the whitefly density is 3-5 individuals/m^2 at the beginning of the vegetation period, it is necessary to release 2-3 times more parasites, which results in the reduction of the capacity of long-term pest management. *Encarsia* application has low effectiveness at an initital pest density of more than 5 individuals/m^2. The best results with *Encarsia* are achieved when the parasite is released on crop varieties with complex resistance to diseases where fungicide treatments have been reduced. The initial pest density being equal, the whitefly infests up to 50% of resistant plants and 75% of non-resistant ones. The average density of the whitefly by the end of the season is up to 30 individuals/plant on resistant varieties and 10 times more on non-resistant ones, while the percentage of larvae parasitized with *Encarsia* is almost equal.

Development of the glasshouse whitefly and *Encarsia* effectiveness is differently influenced by the host plant (cucumber). Thus, the range of the intrinsic rate of natural increase (r_m) varies under optimum conditions from 0.093 to 0.103 on such varieties as Legenda, Sjurpriz, Rodnitchok, Nectar, Mayak BI and hybrid 818x969. In this case Encarsia parasitizes 69-88% of the pest at equal parasite-host ratio (2).

Spider mite. Phytoseiulus is widely used to control the spider mite. Good protection effect is achieved when the predator is released many times into the pest development foci at the rate of 50-100 thousands individuals/ha. Phytoseiulus is reared in specially designed cages (4) allowing to get predators free of plant material. It makes the process of acariphage application more technological and besides, the area under reproduction is reduced.

Tobacco thrips. Harmfulness of thrips on cucumber and sweet pepper is usually manifested after successful biological control of major pests. The intrinsic rate of natural increase of thrips on cucumber in higher than on sweet pepper and constitutes 0.199. In recent years the predaceous mite Amblyseius (received from Dr. P. Ramakers, the Netherlands) has been tested against the pest mentioned. Tests have demonstrated that a single predator release at the initial thrips density 2-3 individuals/leaf in the ratio 1:5 prevented pest development.

Tomato.

Glasshouse whitefly. Encarsia application 3-5 individuals/m^2) at pest density 1 adult/m^2 provides yield protection and results in the presence of low numbers of whitefly at the end of the vegetation period. The release rate of the parasite has to be increased 2-3 times at greater whitefly density (up to 5 individuals/m^2). Encarsia also controls pest reproduction in this case. However, the number of plants colonized by the whitefly may be rather high.

Biological parameters of the whitefly developing in different tomato varieties (Rutcheyok, Orphej, Revermoon, Zenit) don't differ considerably (r_m about 0.060). The level of parasitization of whitefly on different varieties is also almost equal.

Spider mite. The spider mite is not a constant pest of tomato, so Phytoseiulus is used only in certain cases.

Sweet pepper.

Glasshouse whitefly. Though sweet pepper is the least preferable host plant for nutrition of the whitefly (1), the harmfulness of the latter on certain varieties is rather high. The pest does not reproduce on such pepper varieties as Herpa and Novi. The intrinsic rates of natural increase on the varieties Topolek and Podarok Moldovy are 0.035 and 0.008, respectively. These parameters vary from 0.090 to 0.104 in the varieties of Lito, Latino, Lastochka and Rubinovyi (it corresponds to the data on cucumbers). As a rule, varieties preferable for the whitefly are not planted in big commercial glasshouses. Encarsia effectiveness is high on resistant varieties even at considerable pest density.

Grean peach aphid. This is the most dangerous pest of sweet pepper. The local population of Aphidius matricariae has been used for 2 years to control this pest. Its effectiveness in glasshouses (area 1-3 ha) reaches 99%. To control the green peach aphid successfully it is necessary to release 1 parasite against 20 aphids. It takes 3-4 weeks to achieve complete pest suppression depending on the density of the aphids (average release rate is 50.000 parasites/ha). Aphidius is introduced in mummies together with the plants on which it was reared.

The parasite is reared on Schizaphis graminum Rond., the latter being maintained on wheat or barley. This allows to get enough biomaterial on a small area to protect 6 and more hectares of pepper (3). Aphidius r_m is less on S. graminum than on Myzus persicae (0.288 and 0.333, respectively). Transition to the natural host meets no difficulties, aphidophage biological indices being improved.

Spider mite. Harmfulness is less manifested on pepper than on cucumbers, however, r_m is rather high in this crop (0.194). This pest may cause a lot of damage when insecticides are not applied.

Tobacco thrips. As in cucumber pest reproduction on pepper may take place after successful biological control of the aphids and whitefly. High intrinsic rate of natural increase (0.171) of thrips on this crop allows it to achieve considerable density in a rather short period of time.

Studies continue on techniques of Phytoseiulus application against the spider mite and Amblyseius against the thrips on pepper.

Rose.

Rose aphid and green peach aphid. The predaceous gall midge has been tested against aphids on roses. Rose aphid is the most dangerous pest. The intrinsic rate of natural increase is 0.235 even at low temperatures (15°C) and 0.390 at optimal ones. Fundatrices emerge late in February - early in March. The pest develops successfully on all varieties. Aphids are very mobile, can be easily shaken off plants and are quickly distributed in glasshouses. Thus, it is necessary to introduce the predator at least once a week during a month or a month and a half starting from the moment of the first pest occurrence. Positive results were encountered at the predator/prey ratios 1:10 - 1:15. Gall midge application at temperatures lower than 20°C is low effective due to great difference in rates of aphid and predator development.

Green peach aphid has a lower r_m (0.232) and develops for a long time in the foci. Thus, even one release of the gall midge in the ratio of 1:50 will prevent pest reproduction for a month.

Gall midge is mass produced on S. graminum Rond. and Rhopalosiphum padi L. These aphid species do not considerably influence the main biological indices of the predator. It is easy to grow cereals at a wide temperature range. Aphid yield per area unit is 2-3 times higher than from rearing on beans.

Spider mite. This pest appears on roses either in February or in March. Unlike aphids, the spider mite development rate is influenced by the crop variety. Thus, r_m is 0.201-0.223 on the rather resistant varieties Le Rouge et Le Noir, Grand-Nord, Concord; r_m is 0.254-0.273 on such susceptible varieties as Prominent, Eterna and Vivre. Mite preference to some rose varieties is also observed in mixed planting in commercial glasshouses. Phytoseiulus introduction into the spider mite development foci at the ratio of 1:50 on resistant varieties and 1:25 on susceptible ones (50-70 thousand individuals/ha) allows to maintain pest development under damage threshold.

This review gives results of predators and parasites application against pests during the main growth cycle. Their usage during additional growth cycle is under consideration.

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CONTROL OF SPIDER MITES AND THRIPS WITH PHYTOSEIID PREDATORS ON SWEET PEPPER

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Summary

Large scale biological control of thrips on sweet pepper started in 1985. The number of growers using Phytoseiulus persimilis against spider mites and Amblyseius cucumeris against thrips simultaneously is much higher than the number of growers using only P. persimilis previously.

On sweet pepper, biocontrol of red spider mite with Phytoseiulus persimilis has been applied in the Netherlands since the mid-seventies (Woets, 1976), following the successful application in cucumber growing. The method as such proved to be sufficiently effective, but problems with minor pests - mainly Thrips tabaci - impeded the development of IPM programmes attractive to growers.

An IPM-scheme (Ravensberg et al., 1983) based on an OP-resistant strain of P. persimilis (against spider mites), low dosis tetrachlorvinphos (against thrips), pirimicarb (against aphids) and Bacillus thuringiensis (against noctuids) was applied by a slowly increasing minority (max. 60 ha) of sweet pepper growers in the early eighties (van Lenteren, 1985). Export problems caused by pesticide residues in 1984, and the expected withdrawal of tetrachlorvinphos from the market in 1986, made a revision of pest control for this crop necessary.

Growers insisted on the scaling up of biological thrips control with predatory mites, a method tested so far in small experimental plots and since 1980 in a limited number of commercial greenhouses (Ramakers & van Lieburg, 1982). From these experiments it was concluded that Amblyseius cucumeris should be preferred to another sp. tested, A. mckenziei, in spite of the fact that the latter is easier to mass-rear and more tolerant against chemicals. Since A. cucumeris is able to maintain a basic population on sweet pepper independent of its host, this predator can be introduced previous to pest occurrence, and in this way control can be achieved with the early introduction of relatively few predators. The biocontrol company Koppert BV was willing to organize mass-rearing, distribution and guidance. A letter indicating A. Cucumeris to become available in 1985, was sent to 450 sweet pepper growers, of which 120 responded. Only 53 growers (68 ha) actually received this predator in 1985 because of the limited capacity of the mass-rearing. For 1986 the corresponding figures were 118 growers and 140 ha. Figures for 1987 were not yet available when this paper was prepared.

For two seasons, the introduction of this new biocontrol programme was supported financially by the Central Bureau of Vegetable Auctions. The grant allowed systematic leaf sampling (100 leaves per holding per month) to assess the population density of the pest and - especially - of the predator. Monitoring in 1985 (de Klerk & Ramakers, 1986) indicated predator populations to be intact usually until August, when most growers used broad spectrum chemicals against noctuids. Monitoring in 1986 was less intensive because of the larger number of participants. Generally, the programme was successful again, but early (June/July) complications with minor pests, mainly Aphis gossypii and Thrips fuscipennis, were more frequent. Information about 1987 - if available - will be provided during the meeting.

The use of Amblyseius spp. for thrips control seems to be a reasonable alternative to chemical control of this pest, at least for sweet pepper growing. It will be tried to increase the predator's resistance to current insecticides by traditional selection, and maybe in future by genetic engineering.

The most distinct challenge at this moment is whether or not these predators are able to deal with Frankliniella occidentalis, a new thrips pest in European greenhouses, which is very difficult to control chemically. If so, this will be a major stimulus for biocontrol on greenhouse vegetables. If not, we must face another severe threat to our IPM programmes.

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RECENT DEVELOPMENTS IN THE CONTROL OF THRIPS IN SWEET PEPPER AND CUCUMBER.

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Summary

Biological thrips control in sweet pepper by means of the predatory mite *Amblyseius cucumeris* has been rapidly introduced in practice since 1985. In this first year of commercial applications this predator has been released on about 25% of the sweet pepper area (= 240 ha), in 1986 on almost 60%. In general control was satisfying on 80% of these holdings. Control of secondary pests sometimes interfered with the use of *A. cucumeris* because these predators are very susceptible to chemical compounds.
Thrips control in cucumber with *A. mckenziei* was stopped after four years of commercial applications. The method is considered to be unreliable and not yet ready for practical application. Thripstick is applied in cucumber to control thrips since 1986, giving the opportunity also to use *Encarsia formosa.*

1.Thrips control in sweet pepper.

In 1985 commercial application of *Amblyseius cucumeris* for the control of *Thrips tabaci* was started after several years of successful application on an experimental basis in 2-3 commercial sweet pepper holdings (Ramakers, pers. comm.).

The application was strongly stimulated by the demand to export residue-free sweet peppers to the U.S.A.. Residues of certain fungicides and insecticides are not allowed on these fruits, including tetrachlorvinphos,the chemical used for thrips control in sweet pepper. Moreover, tetrachlorvinphos is no longer available since 1986.

The grower's attention was drawn to this new biological control method by publications in the professional magazines and by individually writing them. Close cooperation between the growers/auction organisation (C.T.B.), the Extension Services, the Glasshouse Crops Research and Experiment Station at Naaldwijk and the producer of natural enemies, resulted in a smooth and fast introduction of this new biological control method.

Methods

By means of an applicationform growers could show their interest in applying *A. cucumeris.* From these announcements holdings were selected on which we started. In many cases the situation was considered not to be suitable meaning there were already to many thrips or there were residues present which are lethal to *A. cucumeris* for a long period.

In 1985 introductions were performed in March and April. If possible introductions were made before the occurrence of thrips or if only very few thrips were present. To achieve this, dichloorvos aerosols can be applied to control thrips untill shortly before the release of *A. cucumeris.* First a trial introduction was done on a small part of every holding to see if any lethal residues were left. After checking survival approximately one week later *A. cucumeris* was being released on the whole holding. They were released by sprinkling a few cc of wheat bran with approximately 50-60 predators on every seventh plant in every plantrow, meaning ca. 240,000 predators per ha.

The predatory mites are mass-produced on a substitute *prey,Acaris farris,* grown on wheat bran (Ramakers & v.Lieburg, 1982).

Establishment of the predators was checked by taking a sample of 100 leaves per ha or per (part of the) holding. This sampling was continued every month to monitor thrips and predator populations. At the same time the crop was inspected for thrips damage, especially fruit damage for which the tolerance level is very low. On the basis of the thrips and predator incidence (= % of leaves with one or more thrips resp. predators) and the damage it was decided whether the situation was under control or a chemical treatment was needed to control thrips.

In general the same procedure was followed in 1986. Introductions were mainly made in March. Trial introductions were not done and because of the large scale application, sampling decreased to taking a sample one month after the introduction and further on only when problems seemed to arise.

Results

In 1985 *A. cucumeris* was applied on 53 holdings, covering 68 ha. The predatory mite established well in most cases. However on 11 holdings a second introduction was done because the predator's incidence was less than 10% after 3-4 weeks or because a chemical treatment was applied shortly after the introduction. On 8 holdings it became necessary to control thrips chemically by tetrachlorvinphos- which means the end of *A. cucumeris-* or by dichloorvos because the thripspopulation increased too much in the course of April-July.

In 80% of the cases thripsnumbers stayed very low (incidence under 5%) while the predator's incidence was high (over 50%). A thrips incidence of approximately 20% is considered to be the tolerance level although a strict figure is difficult to give (De Klerk & Ramakers , 1986). At the end of the summer (Aug./Sept.) the control of secondary pests more and more asked for broad-spectred chemicals (table 1) which are incompatible with *A. cucumeris.* However at that time these treatments do not mean that thrips will get a problem for the rest of the culture period, but generally these cases are considered to have had a successful biological thrips control.

In 1986 biological thrips control was performed on 118 holdings, covering 140 ha, out of a total of 240 ha heated sweet pepper crops (= 58%). Introductions succeeded well although in 12 cases a second introduction was necessary because of a chemical treatment with dichloorvos to control thrips or dicofol to control broad mites shortly after the first introduction. In general incidence figures gave the same view as in 1985 although less samples were taken per holding. Thrips control was satisfying on about 80% of the holdings untill August/September. Chemical treatments were applied on 20 holdings in the course of the season where *Thrips tabaci* increased to high levels. This was done by oxamyl applications (systemic action) which is safe to *A. cucumeris* or by dichloorvos aerosols. We learned that the use of the latter could be integrated because predator eggs survive the treatment or another introduction was done. In 7 cases tetrachlorvinphos was used but then residues are lethal to the predator for a long period.

More then in 1985 the control of secondary pests interfered with the use of *A.cucumeris*. *Thrips fuscipennis*, a polyphagous flower thrips, invaded the greenhouses in the summer giving the same fruit damage as *T. tabaci*; in 9 cases this was the reason for a chemical treatment. Also *Aphis gossypii* occurred frequently and heptenophos was sprayed to control them in 16 cases; pirimicarb is not effective on this aphid.

Conclusively it can be stated that the use of *a. cucumeris* has found its position in an integrated pest control scheme in sweet pepper after two years of successful applications.

Because of the susceptibility of *A.cucumeris* to chemical compounds control of secondary pests can cause problems. Invasions of *T. fuscipennis* are difficult to control by the predator, *Aphis gossypii* seems to be a more and more occurring pest organism and compatible insecticides to control these insects are not available. However, treatments against these insects are not directly the end of A. cucumeris if they are well guided and timed. Nevertheless, enlargement of the biological part of the control scheme with an aphid predator (parasite) would make the system much more secure. For additional thrips control Thripstick can be integrated. Selection of a more resistent strain of A.cucumeris could facilitate its use very much and would also give possibilities for thrips control in cucumber.

Table 1 : integrated control scheme in sweet pepper

PEST	CONTROL METHOD	remark/additional control
thrips	Amblyseius cucumeris	dichloorvos* before introduction
spider mites	Phytoseiulus persimilis	fenbutatinoxide
caterpillars	Bacillus thuringiensis	broad-spectred chemicals**/autumn
aphids	pirimicarb/parasites	avoid frequent use of pirimicarb
white fly	Encarsia formosa	pest of minor importance
leafminers	Dacnusa/Diglyphus	pest of minor importance
powdery mildew	bitertanol	pest of minor importance
A. gossypii	heptenophos*	
T. fuscipennis	dichloorvos*, diazinon**	

* - shortly lethal to A. cucumeris (mobile stages)
**- long lethal residual action on A. cucumeris

2.Thrips control in cucumber.

Biological control of Thrips tabaci in cucumber with the predator Amblyseius mckenziei was commercially applied during four years (Ravensberg et al, 1983). Despite intensive guiding, sampling and compatible chemical thrips control we had to conclude that this system was not reliable and satisfying enough for a continuation on a large practical scale. It needed too much attention and help from chemicals, especially in spring, to keep thrips at an acceptable level. Why A. mckenziei was not successful in controlling thrips on commercial holdings, in contrast with small trials (Ramakers, 1980;Ramakers & v. Lieburg, 1982), is not understood. In this respect further research is needed.

Thripstick

An alternative method to control thrips in a biological pest control scheme is the application of Thripstick. This has been used for the control of Thrips tabaci in the U.K. since 1981 (Binns et al, 1982; Helyer et al, 1983).

The active ingredients of Thripstick are polybutenes, synthetic hydrocarbon polymers with a high viscosity. On ageing this material stays sticky. To have an effective control a synthetic pyrethroïd (cypermethrin) is mixed with the Thripstick solution. This can be done by the producer (as in the U.K.) or by the grower (as in the Netherlands). The effect of the additive is shown in an experiment in a commercial holding in 1984 (Fig.1).

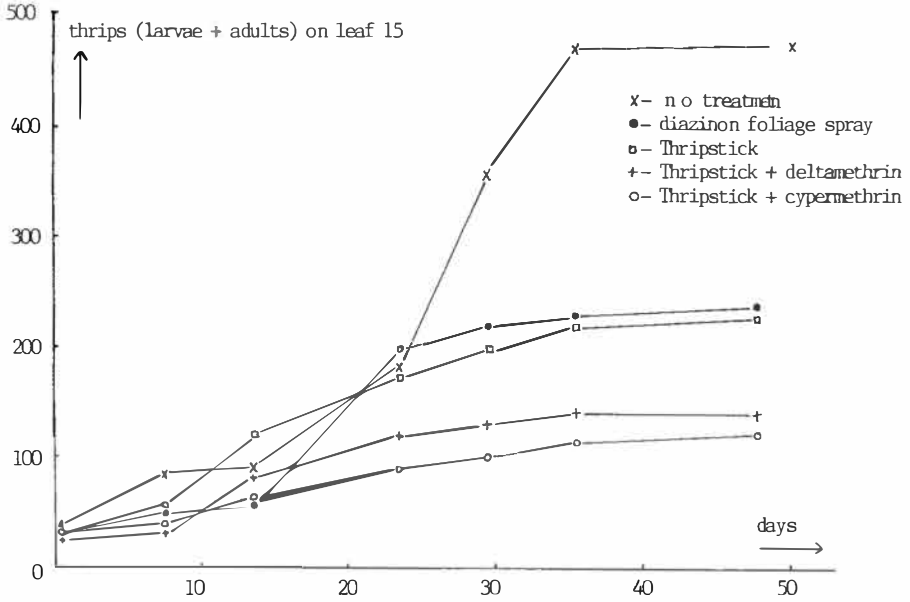
The Thripstick-pyrethroïd combination is applied on the plastic sheetings on the floor to catch the thrips which drop to pupate. A strip of 30-40 cm on both sides of the plantrow has to be sprayed. A preventive application is advised on clean sheetings, just before or after planting. Trials during three years showed that control can last for about three months, a second application might be worthwhile. The tackiness mainly decreases because of dust and old plantmaterial falling on the floor and by walking on it.

Thripstick has been registered in the Netherlands in 1986 for the control of thrips in cucumber and sweet pepper crops.

Trials in the summer of 1986 on holdings with a second cucumber crop showed also an effective control of *Frankliniella occidentalis* which also drops on the floor.

The use of Thripstick also gives the possibility to apply *Encarsia formosa* to control white-fly which in the past was impossible because of the chemical thrips control.

Fig. 1. The control of *Thrips tabaci* with Thripstick (and additives) on a commercial cucumber holding in Sept.-Oct. 1984.



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OBSERVATIONS ON THE PREDATORY AND PHYTOPHAGOUS HABITS OF DICYPHUS TAMANINII WAGNER (HETEROPTERA; MIRIDAE)

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Summary

Dicyphus tamaninii Wagner is a common species in non or slightly sprayed vegetable crops in El Maresme (NE of Spain). In this paper, some data on the predatory feeding preferences of the mirid bug are included. Phytophagous habits are displayed only when prey is scarce. Some common vegetable crop pests other than greenhouse whitefly are also preyed on by *D. tamaninii* and preliminary results on the developmental period of bug nymphs, feeding on whitefly are obtained. The possibilities of employing the mirid bug as a biological control agent in field and glasshouse vegetable crops are discussed.

Introduction

A wide diversity of greenhouse whitefly predators have been identified in non or slightly sprayed vegetable crops in El Maresme (NE of Spain), some of them belonging to Miridae (Bordas et al. 1985 , Albajes et al. 1985).

In field tomato crop experiments, carried out between 1983 end 1986 a major role of a mirid bug, *Dicyphus tamaninii* Wagner in regulating *Trialeurodes vaporariorum* Westwood populations was to be observed (unpublished results). However, a variable number of tomato fruit were damaged by mirid bug punctures. Injury levels in tomato fruits were not strictly related to mirid bug numbers and a preliminary hypothesis was established - the bug prefers whitefly prey and only when alyrodid numbers fall below a threshold density does switch to phytophagus feeding.

The main aim of this paper is to confirm or reject this hypothesis by means of some laboratory experiments and to obtain some additional data on the predatory behaviour of *D. tamaninii* in order to evaluate its potential as a biological control agent in field and protected vegetable crops.

Material and Methods

The mirid bugs and whitefly used in these tests were greenhouse reared on *Nicotiana tabacum*. Rearing populations were periodically renewed with field individuals. The remaining species used in these tests were collected in the field.

Experiments were conducted in an environmental cabinet at 22 ± 1 ºC and 16 h photophase.

Experiment 1. This experiment was designed to study the feeding preferences of a *D. tamaninii* nymph in the presence of a tomato fruit and a variable number (5, 20, 100) of whitefly nymphs ($N_2 + N_3$) or adults. A potted tomato plant with a full-grown leaf (nymph test) or with two young leaves (adult test) and a semi-ripe tomato fruit were placed in an aired plastic cage of 52 x 42 x 50 cm. A predetermined number of newly emerged whitefly adults (5,20 or 100) were introduced into each adult test cage. In the nymph test, sufficient whitefly nymphs were removed from the tomato leaf in order to maintain the desired number of $N_2 + N_3$ (5, 20 or 100).

A 3rd instar nymph of *D. tamaninii* was introduced into each cage. Control consisted of cages without mirid bug and 50 whitefly ($N_2 + N_3$ or adults) and one tomato fruit.

Four days after the introduction of the bug, the following data were recorded in for each cage: the number of dead whitefly (nymphs or adults) and the number of discoloured yellowish spots in the tomato fruit. Only cages where the bug nymph was recovered alive after the four days have been considered in the results.

Ir order to compare the numbers of whitefly preyed upon and injuries to tomatoes with the Duncan multiple range test, data were transformed by $\sqrt{x+\frac{1}{2}}$.

Experiment 2. This experiment was carried out to evaluate the developmental period of mirid bug nymphs at 22ºC with no shortage of prey. A new-born bug nymph was introduced into a plastic cage of 23 x 11.3 x 6.3 cm containing a tomato leaf with approximately 100 2nd and 3rd instar whitefly nymphs. The petiole was covered with wet wadding in order to prevent the leaf from prematurely drying. The leaf was changed every three days until adult bug emergence and the number of empty whitefly nymphs (preyed nymphs) was recorded. Cages where bug nymphs did not reach adult instar have not been considered in the results.

Experiment 3. This experiment was carried out to establish a list of potential preys of *D. tamaninii*. A tomato leaf, with a known number of prey individuals, was placed in an aired plastic cage of 52 x 42 x 50 cm. Twelve nymphs or adults of *D. tamaninii* were introduced. After 4 days the number of dead and living preys was counted. In order to prevent premature leaf drying, its petiole was covered with wet wadding. A cage with preys but without a mirid bug was installed as a control.

Preys offered to adult bugs and nymphs (N_3) included some of the most common pests of tomato crops: *Autographa gamma* or *Chrysodeixis chalcites* eggs, *Heliothis armigera* eggs, *Liriomyza trifolii* larvae, *Macrosiphum euphorbiae* nymphs and adults. *Tetranychus* sp. adults and nymphs, *T. vaporariorum* eggs, nymphs and adults.

Results and Discussion

A positive functional response of *D. tamaninii* nymphs to prey density (whitefly)may be observed (figures 1 and 2). On the contray, injuries in tomato fruit were inversely related to nymph and adult whitefly densities. Injuries recorded in the control (without the bug) were probably due to field bug populations. In figure 2 the number of preys consumed was lower, and that of injuries higher than in the figure 1. Whitefly adults are probably less suitable preys for bug nymphs of *D. tamaninii* than nymphs. Moreover, these could predate on whitefly eggs laid by adults.

These results confirm the initial hypothesis. *D. tamaninii* nymphs prefer prey (*T. vaporariorum*) to tomato fruits and only when prey density is excessively low do they switch to phytophagous feeding. This behaviour is not entirely unusual seeing that Sanford (1964) pointed to a similar hypothesis for the mirid bug *Antractotomus mali* (Meyer) in orchards.

The mean developmental period of the mirid bug nymphs under the experimental conditions detailed above was 21.85 ± 0.56 (SD) and the number of whitefly N_2 N_3 preyed upon by a nymph during its development was 57.3 ± 2.02 (SD) (An average of 13 nymphs).

Both adults and nymphs of D. tamaninii preyed on all preys offered confirming it as a polyphagous predator. Many other taxonomically close mirids have been pointed out as polyphagous predators by several authors (Viggiani, G. 1971; Wheeler Jr., A.G. 1975; Kowals'skaya, T. 1983; Tsybulskaya, G. 1980). This kind of predator as has been stated by (Hagen, K.S. 1976), may be valuable against pests in short-duration crops. From this wiewpoint, D. tamaninii may be useful in field and protected vegetable crops. However, further research is necessary to determine the impact of this bug on field pest populations.

In fact, in some field experiments carried out between 1983 end 1986 a major role of D. tamaninii in controlling whitefly populations on tomato crops was assessed when no, or few, insecticides were applied.

In protected spring tomato crops, where Encarsia formosa Gahan and selective sprayings are used, D. tamaninii and some other mirid species are usually present during the final weeks of cultivation. In this situation, E. formosa is held to be the main element responsible for maintaining low whitefly populations, but questions should be asked about the role of the mirid bugs on whitefly and other pest population dynamics.

With current knowledge of the behaviour and feeding habits of D. tamaninii, three main questions about its possibilities as a biological control agent may be underlined:

1. Its negative influence on tomato quality. The risk is higher when the mirid bug is abundant and the prey (pest) population scarce, according to some previous (unpublished results) and the present ones. Since insecticides affect the bug a greater extent than the whitefly, careful management of the number and timing of sprayings may be considered in order to prevent outbreaks of both populations. In fact two sprayings with a non persistent insecticide have proved sufficient to prevent bug and whitefly injuries in a field tomato crop.

2. Risks associated with its potential as a vegetable disease vector. Many references to the role of mirids as disease vectors may be found in the literature, none of them related, however, to D. tamaninii. A detailed study of this question should be carried out in field and laboratory conditions.

3. Phytophagous vs. predatory feeding in crops other than tomato. No injuries to cucumber crops have been recorded when the mirid was allowed to act in a greenhouse in order to control whitefly populations. Other experiments with bean and ornamental crops are to be carried out.

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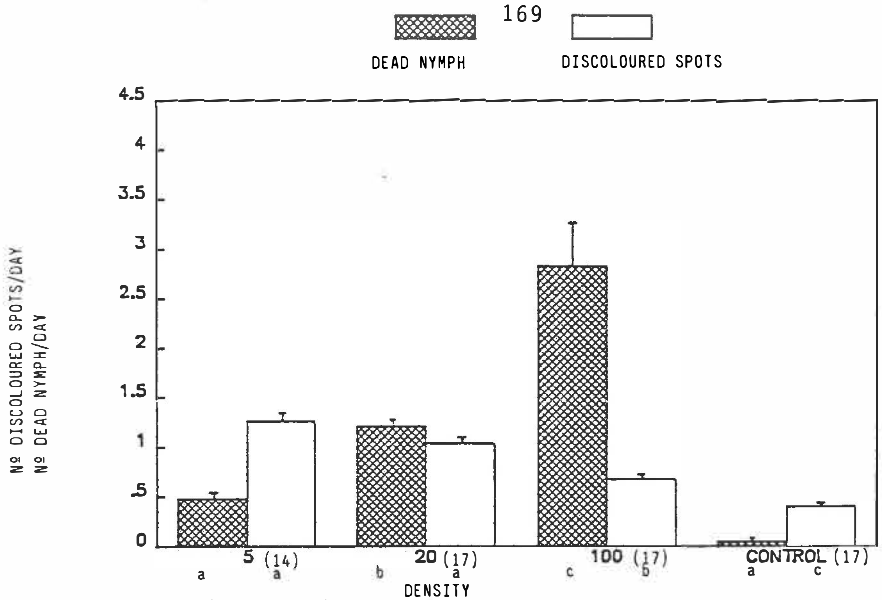

Figure 1: Number of dead whitefly nymph and discoloured yellowish spots on the tomato fruit at different prey densities. Means ±SE. Means followed by the same letter are not significantly different (P > 0.05). Number of replicates are shown in parentheses.

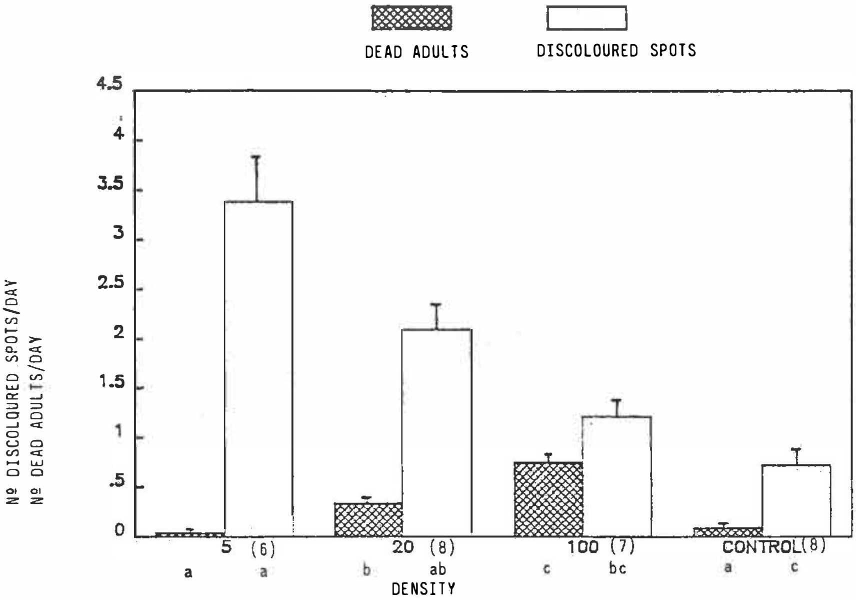

Figure 2: Number of dead whitefly adults and discoloured yellowish spots on the tomato fruit at different prey densities. Means ± SE. Means followed by the same letter are not significantly different (P > 0.05). Number of replicates are shown in parentheses.

POSSIBILITIES AND PERSPECTIVES OF THE BIOLOGICAL AND INTEGRATED CONTROL OF THE TWO SPOTTED SPIDER MITE IN THE MEDITERRANEAN GREENHOUSE CROPS

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Summary

The authors report on the present state of biological and integrated control programmes carried out in protected crops of the Mediterranean area against the two spotted spider mite and discuss the future perspectives of the methodology in that region.

1.1 Introduction

It is widely known that for a certain amount of years the biological control against the two spotted spider mite has been employed with releases of *Phytoseiulus persimilis* Athias-Henriot on several hectares of heated greenhouse crops (cucumber, tomato, sweet pepper, roses, etc.) in different regions of the world (van Lenteren, 1985).

The predator is artificially reared and no natural sources of development can be normally found outside the glasshouses. Nowadays several firms produce this phytoseiid commercially and sell it to the growers in order to employ it into commercial greenhouses on a vast scale.

Rearing techniques are variable and not widely known as the most important commercial firms don't intend to reveal them in details because of trade competition. However they are mainly of two kinds (Scopes and Pickford, 1985; Fournier *et al.*, 1985). Of these two, the French method, got ready at the "Station de Zoologie et de lutte biologique" of Antibes (France), might come up to be the most suitable on to rearings to be carried on in various areas.

The predators are packed in plastic bottles containing wheat, closed by means of screw cap-like cover with gauze, so that supplying the causes no mortality could occur when storage on transport are carried at 7-10°C. Since 1982 *P. persimilis*, in fact, has not been delivered on leaves any longer but on artificial substrate, which has made its introduction possible in any required ratio and has wholly excluded the risk of other pests and diseases introduction.

In the heated greenhouses of Central and Northern European countries the employment of this predator has been widely accepted in operative practice. Such a success is mainly due to the significant social and cultural development of the local populations and to some suitable bio-ecological aspects (temperature, relative humidity, biology of the prey and of the predator in the greenhouses). On the other hand in the Mediterranean area the production and employment of the phytoseiid can result easierly conditioned than elsewhere.

In this latter environment the high summer heats and the low relative humidity registered in summer, the rigours of winter and other factors give serious problems as far as the employment of the predator is concerned.

Moreover the simultaneous appearance of other pests prospects for serious difficulties due to the impossibility of integrating some chemical means with the action of the phytoseiid.

Now we are going to examine, briefly and in succession, the present state of the situation referring to the main greenhouse areas of the Mediterranean basin, and the future perspectives linked to the employment of the predator in these countries.

1.2 Present employment of *Phytoseiulus persimilis* in the countries of the Mediterranean basin

In France the phytoseid is reared artificially and it is distributed (Koppert France and other firms) on about 195 ha of cucumber (van Lenteren, l.c.). It is possible that the surface pointed out above is nowadays increased and that the present state is different.

In this country the employment of the predator doesn't seem to differentiate its problems from those commonly emerging in Central Europe.

As far as Spain is concerned no news has been given on the commercial employment of the phytoseiid. In this country the predator mite has been tested in the Canarias Isles on rose and has given positive results (Peña Estévez, 1985). The phytoseiid was imported from England.

In Greece *P. persimilis* is imported from the Netherlands (Koppert B.V.) by the Salonicco firm "Mr Karantonis Skydra Edessa". As far as this matter is concerned Kozirakis (1983) states that in various Greek localities about 16 ha of cucumber are controlled by the biological method.

In Israel the predator is reared and distributed by the firm "Biological Control Insectaries" in the Kibbutz Sede Eliyahu (Nakash, 1983). In this area the mite has been tested on strawberry (Sachs *et al.*, 1983) and other crops (Bitton and Nakash, 1983).

In the operative practice it has been introduced, with an acceptable success in about 60 ha of water melon (van Lenteren, l.c.).

As far as Italy is concerned one must tell that at present the methods of biological and integrated control against the two spotted spider mite in the greenhouse crops haven't still entered in the operative practice. We have got pieces of news on the importation of small quantities of *P. persimilis* (Koppert B.V.) in some Italian regions. In Sicily the production of this predator has started this year in the province of Ragusa.

From the experimental point of view the action of the cecidomyiid *Therodiplosis persicae* Kieffer and of *P. persimilis* has been tested. Both these predators are present in nature in Italy.

T. persicae has proved to be very efficient in various crops (Vacante, 1981). But it can be employed only in winter because the natural spring appearance of *Aphanogmus parvulus* Roberti, an hymenopter proctotrupid hyperparasite of the cecidomyiid, reduces its utility decimating its population from May onwards (Vacante, 1984). As far as *P. persimilis* is concerned two research patterns have been followed: 1) Evaluation of the free contribution from the natural populations of phytoseiid that on conditions of non intervention with non selective insecticides develop spontaneously in greenhouse crops; 2) Calculated and planned introduction of the predator in various crops.

The former hypothesis has been evaluated in rose greenhouses (Vacante and Firullo, 1983) and gerbera greenhouses (Vacante and Tropea, 1986). On the latter crop there have been extremely positive results.

The planned introduction of the predator has been tested on melon and paprika (Vacante and Calabretta, 1983), on strawberry (Vacante, 1985; Nucifora and Vacante, 1985), cucumber and bean. In all the cases native populations of the phytoseiid have been employed. These populations were partly taken from those reared in the insectarius of the "Istituto di Entomologia agraria" of the Catania University and partly gathered from the spontaneous flora (*Ricinus communis* L.).

We haven't received any other piece of news as far as other countries of the Mediterranean basin control plans are concerned.

1.3 Future perspectives

The future programmes of biological and integrated control of the two spotted spider mite in the protected crops of the Mediterranean area provide fundamentally the usage of P. persimilis. The phenomenon is expanding constantly and it interests various countries.

But as far as these countries are involved we should point out exactly the conditions of the countries in which the production and usage of the predator have yet been entered widely both in the commercial stage and in the operative practice (France), and the ones of the others in which they are either in a developping stage (Israel, Italy) or partially absent (Greece, Spain).

French greenhouse crop conditions, very similar to the Netherland's and to the England's ones, must have encouraged the transfer of a great deal of technical knowledges already tested elsewhere in the past years, and therefore the affirmation of the new control method. It seems us right to maintain that this new method will found constant approval in France and it won't meet particular problems which could limit its diffusion.

Instead in other regions of the Mediterranean basin the phenomenon seems to be more complex since the termo-hygrometric conditions present in the unheated greenhouses influence the bio-ecology of the pest and the predator and obstacolate the integral adoption of the already known techniques.

In our environment the production and usage of the phytoseiid make rise various problems. These problems have suggested a careful check of all the aspects linked to the biological control of the crops and advised against the adoption of a common and generalized method, inviting, on the contrary, to lead the research toward local solution.

Hence in Israel the hypotesis of the predator importation has been cast off and nowadays it is reared in termoconditioned environments (Nagask, l.c.) and commercialized by a local organization. The employed strain is probably similar to that used in the Netherlands (Koppert B.V.).

As far as the techniques adopted in the introduction of the predator in the various crops are concerned there aren't definitive information. We are able to state that in this region solid and wide possibilities for the new technology development exist.

As far as Greece and Spain are concerned news on a local production of the phytoseiid has not reached us. It is possible that in this region the pest has not been introduced yet and in the next future it should be imported from Central Europe.

In Italy the phytoseiid is in part imported from the Netherlands (Koppert B.V.) by the Cesena "Cooperativa Ortofrutticola" (Bologna), and in part produced in Sicily in Vittoria (Ragusa). The local production of the predator has strarted this year and it is based on the rearing of a native strain. It is anyway a limited production carried out thanks to funds given by the Sicilian Organisation for the Agricoltural Development and at the present simply destined to demonstrative pilot-firm.

Other centres of production financed by local Organisations are going to be born in Sicily.

In this region the possibilities of applying the new control method in the operative practice seem to be solid and offer considerable possibilities. Nevertheless they need development programmes which require a certain amount of time.

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SUITABILITY OF TWO STRAINS OF SWEET PEPPER, CAPSICUM ANNUUM L., FOR THE GREENHOUSE WHITEFLY, TRIALEURODES VAPORARIORUM (WESTWOOD), IN HUNGARY

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Summary

The greenhouse whitefly, Trialeurodes vaporariorum, is a pest in sweet-pepper crops in Hungary, but not in the Netherlands. Research done in Hungary shows that the whiteflies lay more eggs, have a shorter developmental period and a lower mortality during development on a Hungarian sweet-pepper cultivar than on a Dutch one. The results of the experiment are compared with results obtained in the Netherlands.

1. Introduction

The greenhouse whitefly, Trialeurodes vaporariorum (Westwood), is a pest in sweet-pepper crops (Capsicum annuum L.) in greenhouses in Hungary. In the Netherlands the whitefly is a pest in tomato crops where it can be controlled successfully with the parasite Encarsia formosa, but it never creates problems in sweet-pepper crops: population development is slow in this crop and populations usually die out soon after immigration in a sweet-pepper crop occured (1).

This situation reflects the situation in eastern and western Europe. It has been found that cultivars from Bulgaria and Csechoslovakia are less resistant against whiteflies than cultivars from America and the West-Indies which are also used in western Europe (2).

Experiments, however, have been done with only one strain of whiteflies at a time, so it was not possible to discriminate between two possibilities: the sweet-pepper cultivars used in Hungary may be better host plants for the whiteflies because of their different breeding history but on the other hand can it be that the whiteflies are adapted to a normally "bad" host plant. To discriminate between these possibilities the following experiment was performed: Two cultivars of sweet pepper, one commonly used in the Netherlands and the other commonly used in Hungary were grown in both countries. On these plants the development of the greenhouse whitefly from egg to adult was measured. In this way two strains of whitefly were tested on two strains of sweet pepper.

This paper describes the results obtained with the Hungarian whitefly-strain.

2. Material and methods

Whiteflies were collected on sweet pepper, cultivar Angeli emléke, at the Lenin MgTh in Mindszent. The sweet-pepper plants used in the experiment were also grown there. The cultivars used were Tisana, commonly used in the Netherlands, and Angeli emléke, commonly used in Hungary. After the experiments the plants were approxiamately 25 cm. (Tisana) and 32 cm. (Angeli emléke) tall and had on average 14 respectively 13 leaves.

The experiments were done in a small greenhouse. The average light-period was 15 hours, the average temperature 24.4 ± 5.8°C and the average humidity 95.5 ± 9.2 R.H..

Whiteflies of less than 24 hours old were collected and allowed to oviposit for four days on tobacco (cultivar Samson). After this period they were under anaesthetization put into small leafcages which were clipped on fully grown leaves (numbers 4 - 6 counted from the top of the plant) for a 24-hours period. Each leafcage contained on average one male and three females and 50 leafcages were used.

After the removal of the whiteflies the leaves were scanned daily with a stereomicroscope mounted upside down on a chemical stand to determine the stage of the whiteflies. For larval stages and a pupal stage (including the prepupa) were distinguished (3).

From the time that the mobile first larval stage began to settle permanently at one place on the leaf maps of the leaves were made which made it possible to recognize individuals (see figure 1). The settlement of the first larval stage took a time-span of several days with often resettling after periods of probationary settling, a phenomenon already observed on less preferred host-plant species (4).

The following parameters were determined:

- the number of eggs laid (per female)
- the developmental time per stage and the total developmental time from egg to adult. The developmental time of the egg and the first larval stage were calculated together.
- the 50% developmental time from egg to adult
- the percentage mortality per stage, both as a percentage of the total number of eggs laid and as a percentage of the number of individuals entering a stage.

3. Results

On Tisana, the Dutch cultivar, the whiteflies laid 661 eggs, which means 4.4 eggs per female during 24 hours. On Angeli emléke, the Hungarian cultivar, more eggs were laid: 834, which means 5.6 per female during 24 hours.

On Tisana the development of 461 eggs on 19 leaves was followed, on Angeli emléke the development of 561 eggs on 23 leaves. The leaves of Tisana were on average smaller than the leaves of Angeli emléke (26 versus 32 ^{2}cm.). This means that the initial density of the whiteflies on both cultivars was the same. It was about one egg/^{2}cm.

On Tisana 25 individuals completed their development (5.4%), on Angeli emléke 354 individuals completed their development (62.9%). The total developmental period of the larvae that became adults was 34.3 days on Tisana and 29.3 days on Angeli emléke. The largest differences were found in the final stages: The fourth larval stage on Tisana lasted 4.6 ± 1.9 days and on Angeli emléke 2.9 ± 1.0 days, the pupal stage lasted on Tisana 8.2 ± 2.2 days and on Angeli emléke 6.6 ± 1.3 days (see figure 2).

The 50% developmental time from egg to adult was 34.0 days on Tisana and 29.0 days on Angeli emléke.

On Tisana the highest mortality occured in the third and fourth stage. In nearly all the stages the mortality was much higher on Tisana than on Angeli emléke, were the mortality was more equally spread over the different stages (see figure 3).

4. Conclusions and discussion

The results show why the whitefly will become a pest in sweet-pepper crops in Hungary and not in the Netherlands. On the Dutch cultivar less eggs are laid, the development is slower and the mortality during the developmental period is higher than on the Hungarian cultivar. For the Hungarian whitefly the Dutch cultivar is a bad host plant.

During the same experiment in the Netherlands different results were obtained. On Tisana the Dutch whiteflies laid 3.2 eggs/female during 24 hours, on Angeli emléke 2.8 eggs/female per 24 hours; the developmental period of the individuals that became adults was 27.4 days on Tisana and 27.2 days on Angeli emléke; the mortality during the development was 78% on Tisana and 76.5% on Angeli emléke. For the Dutch whitefly-strain both sweet-pepper cultivars did not differ for the parameters measured. It were both relatively bad host plants.

Data obtained in 1978, however, show that in nine years the whiteflies in the Netherlands have become slightly more adapted to sweet pepper. Both the number of eggs laid per female during 24 hours and the survival during the developmental period have increased, while the developmental period remained the same (1). Perhaps the Hungarian whiteflies are already more adapted to sweet pepper but are also more vunerable for minor differences between the cultivars that the Dutch whiteflies cannot detect.

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Figure 1: Leaf map showing the position of the larvae of Trialeurodes vaporariorum on a leaf of the sweet-pepper cultivar Angeli emléke. All larvae were number, the black dots indicate larvae that did not complete development.

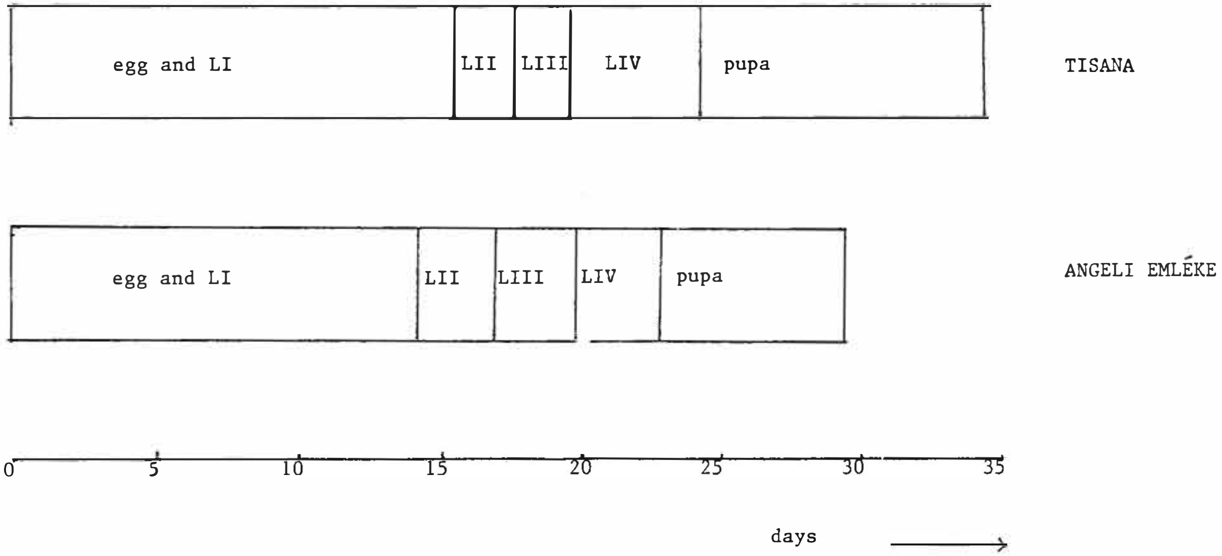

Figure 2: Average developmental period (in days) of the different stage of whitefly on both sweet-pepper cultivars. Only larvae that completed development have been included in the figure.
The codes within the bars indicate the stages. LI is the first larval stage etc..

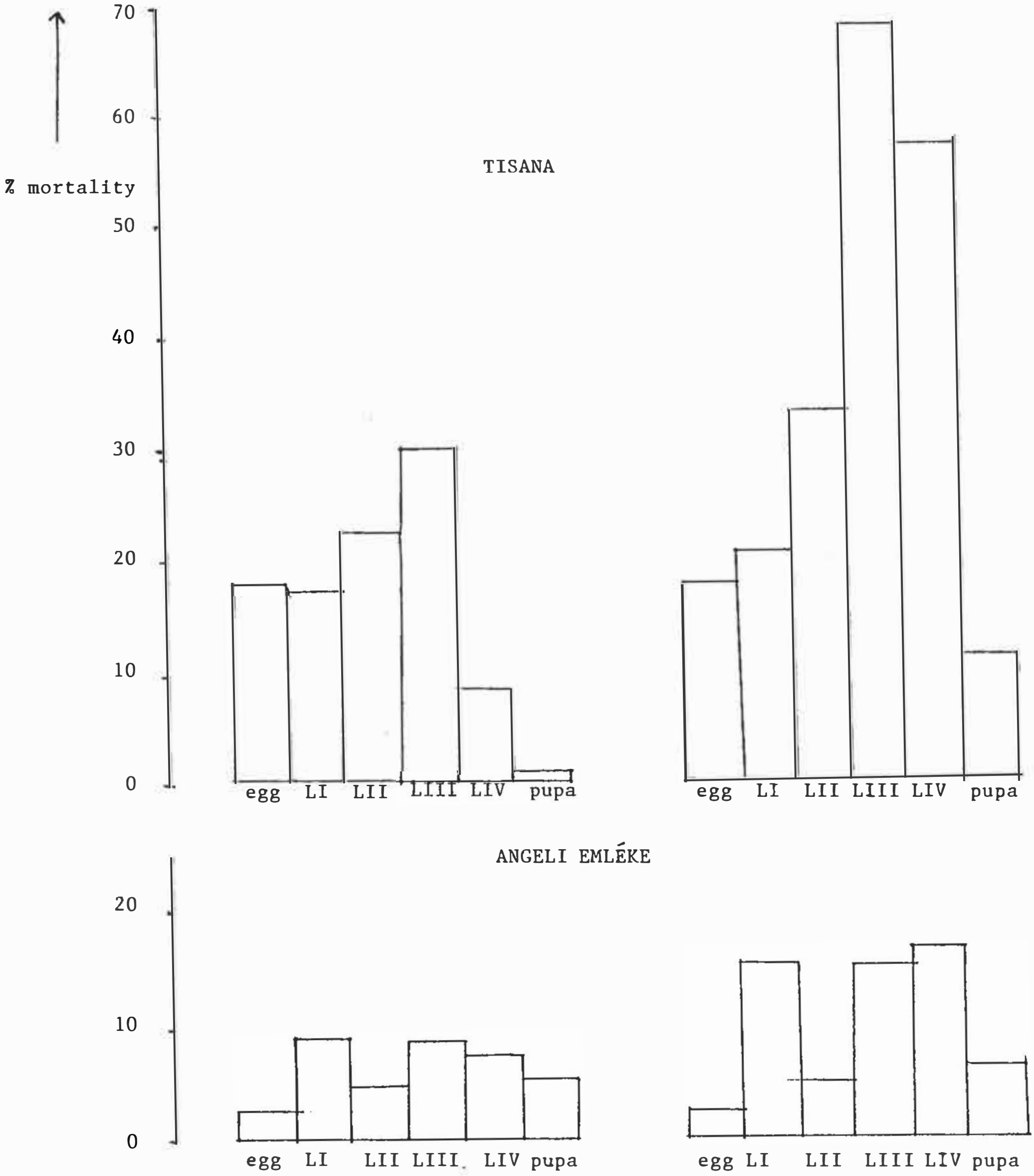

Figure 3: Mortality of the different greenhouse-whitefly stages on the two sweet-pepper cultivars as percentages of the total number of eggs (left) or the total number of individuals entering a stage (right).

THE ROLE OF PESTICIDE RESISTANCE TESTING IN THE BIOLOGICAL CONTROL OF GLASSHOUSE WHITEFLY

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Summary

Data from standard pesticide resistance tests on glasshouse whitefly were used to prepare graphs and tables from which the resistance factor of a whitefly population may be determined from limited-dose resistance tests. These tests are attractive to the entomologist because they are quick and need little labour, and to the grower because they are cheap. The information obtained is useful for integrating pesticides with natural enemies and for encouraging the wider adoption of biological pest control.

1.1 Introduction

Pesticide resistance in glasshouse whitefly (Trialeurodes vaporariorum) (Westwood) has increased during the past decade[1] and has encouraged many leading British growers of cucumbers and tomatoes to use Encarsia formosa (Gahan), the parasitic wasp of whiteflies[2]. Growers of ornamentals have always had a wider choice of pesticides against whiteflies than growers of edible crops but many of them are now finding that resistance is a major problem and they also are having to consider using integrated pest management (IPM) programmes. Encarsia is generally very successful in Britain but the parasities can fail for a variety of reasons; in this event, growers resort to partial or complete pesticide programmes for control of the pest. These growers value information on the resistance spectrum of their whiteflies so that the best choice of pesticide can be made.

It is a relatively simple task to test 'normal' doses of pesticide against whitefly larvae and to decide whether or not the pesticide is failing. However, such a limited-dose observation does not reveal the heterogeneity of the population nor its specific degree of resistance (homogeneity). This information is required if a pesticide is to be used to its full potential. These features are better revealed in a standard resistance-test[3] which produces data for log-probit analyses from which the resistance factor (RF) of the population can be calculated. This test is laborious and therefore expensive and is generally too costly for growers. However, they might be interested in a cheaper test, especially if the result can be related to a resistance factor.

Since 1971, populations of whitefly have been tested at the ADAS laboratories at Wye by the standard method[1] for resistance to up to four insecticides, representative of the major chemical groups (Table 1). In each test, the resistance factor (RF) was calculated as follows:-

$$\mathrm{RF} = \frac{\mathrm{LC}_{50} \text{ of first instar larvae of test population}}{\mathrm{LC}_{50} \text{ of first instar larvae of a standard pesticide-susceptible population}}$$

The dose-range tested usually included half-normal, normal and twice normal doses. Larval mortality for two doses of each chemical was graphed against the resistance factor for each population (Table 1).

Table 1. Doses of pesticides used to provide data for graphs

Pesticide	Chemical Group	Concentration (ppm) of pesticide		
		Half-normal	Normal	Twice-normal
Malathion	Organophosphorus (OP)	563	1125	-
DDT	Organochlorine (OC)	338	615	-
Pyrethrum/ resmethrin	Short persistence pyrethroid (SPP)	-	581	1162
Permethrin	Persistent pyrethroid (PP)	-	125	250

1.2 Results

Graphs produced from data for malathion and to a lesser extent DDT, showed a wide scatter of points compared with those of pyrethrum/resmethrin or permethrin. However, in each graph there was a curvilinear relationship between per cent larval mortality and resistance factor. The statistical calculations of these regressions are complicated and are at present under investigation by a statistician. However, regression lines have been temporarily fitted by eye and from these curves it was then possible to read the likely resistance factors against the full range of larval mortalities caused by the specific dose of pesticides (Tables 2 and 3). Limitation on space in this paper does not allow the publication of graphs, but they will be shown at the oral presentation of this paper in Budapest.

Table 2. Resistance factors related to mortalities of first instar whitefly larvae treated with malathion or DDT

Per cent kill	Resistance factor by pesticide dose			
	Malathion		DDT	
	Half-normal	Normal	Half-normal	Normal
100	1.0	1.0	1.0	1.0
90	1.2	3.6	1.4	1.5
80	2.8	8.5	3.3	3.8
70	4.8	15.9	5.2	6.0
60	8.1	31.6	8.1	9.0
50	16.0	>40.0	11.0	14.1
40	44.2	>40.0	15.0	21.0
30	>45.0	>40.0	19.9	32.6
20	>45.0	>40.0	27.8	>40.0
10	>45.0	>40.0	42.0	>40.0

Table 3. Resistance factors related to mortalities of first instar whitefly larvae treated with pyrethrum/resmethrin or permethrin

Per cent kill	Resistance factor by pesticide doses Pyrethrum/resmethrin Normal	 Twice-normal	 Permethrin Normal	 Twice-normal
100	1.0	1.0	1	1
90	1.5	5.0	50	100
80	2.6	10.0	80	250
70	5.1	15.0	180	500
60	7.8	21.0	400	800
50	10.0	30.0	650	1200
40	14.0	41.0	1050	1850
30	20.4	58.0	1650	2900
20	30.0	91.0	2650	4900
10	52.0	>130.0	5400	>8000

2. The future of limited-dose testing

The data in Tables 2 and 3 may be used to forecast the best pesticide for the grower to use and with experience, the life of the pesticide may be forecaste also. Because the limited-dose test is less laborious and requires fewer facilities than the standard test, entomologists will be able to test more populations than hitherto. Because the test is cheaper, it is more attractive to the grower who is then more likely to ask for a test on his population. There is likely to be an increase in information available on insecticide-resistance and this could almost certainly be used to encourage wider use of natural enemies.

3. Ideas for collaborative research work

(i) Graphs and tables should be prepared for other chemical groups (eg carbamates, growth regulators).

(ii) Limited-dose tests could be used to test the integration of half-doses of pesticides that are at present considered harmful to natural enemies; it may not always be necessary to obtain full chemical control of whiteflies during IPM. It may also be possible to use the information to resurrect "defunct" pesticides.

(iii) Information from using the tests should be pooled to enhance the common experience.

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A SYSTEMS MODEL FOR HOST PLANT-WHITEFLY-ENCARSIA RELATIONSHIPS TO INVESTIGATE OPTIMAL BIOLOGICAL CONTROL STRATEGIES.

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I. Introduction

Systems models which simulate interspecific interactions and optimal pest control strategies are based on population models. Recently, Xu et al. (1981) have developed a dimension-changeable matrix model to incorporate age structure under varying conditions. Its continuous form was presented by Liu & Xu (1982).

In the dimension-changeable matrix model, relative age was used instead of a physiological time scale to incorporate the effect of varying conditions (e.g. temperature) on population dynamics. The advantage is that (1) The calculation of relative age is based on calendar time. It has the advantage as stated by Southwood (1978):" As most biologists can only visualize their population against calendar time, the use of physiological time makes more difficult an intuitive check on the output of the model." (2) Errors originated from approximation in calculating accumulated temperature effects can be diminished. (3) It has a more generalized form. That is, the z (physiological age in Barr's paper) can have a different scale than t, therefore, other conditions than ages in physiological time scale can be introduced. A systems model based on this population model will maintain these advantages. This is one of the reasons for developing this systems model.

Researches on the population ecology of greenhouse whiteflies and whitefly-Encarsia relationships have greatly developed during these last few years. Data concerning host plant and temperature influence on whitefly population parameters, Encarsia population parameters, whitefly-Encarsia relationships, movement and searching behaviour of the Encarsia wasps, the influence of various release ratio to Encarsia movement and parasitism,...etc. are now available for model building .

Control of whiteflies in greenhouses by Encarsia is one of the well known successes in the field of biological control. The application of this biological control program is now extended to various countries and under different conditions. In application, however, some difficulties were encounted. There are also different methods of introducing the wasps, i.e. the "pest in first" method and the "Banker plant system" method in England,

and the Dutch method. Until now there are no detailed considerations on the population dynamics of the insects and their interactions. It is only possible to evaluate relationships and release methods under various conditions by model simulations.

From this systems model, when applied to the whitefly-*Encarsia* relationships, the following questions are expected to be answered:

1. The patterns of whitefly population dynamics on different host-plant species, temperature and initial population densities.
2. The effect of various E:T ratio on biological control under different temperature regimes and initial whitefly densities.
3. Evaluation of the different control methods.
4. Tolerence of different control methods to whitefly immigrations. Stability of insect populations.

Thus, based on a more in depth understanding, we may be able to find out strategies of optimal biological control under different conditions.

II. The Systems Model

The systems model can be roughly outlined as follows:

(1) Read data; the developmental duration time, survivourship and fecundity of whiteflies on different host plants; duration time, survivourship and fecundity of *Encarsia.*

(2) Input;
number of days for prediction,
species of host plants,
initial population density and age structure of whiteflies,
temperature sequence,
dates of *Encarsia* introductions and its abundance.

(3) Then for each day of prediction, the developments of whitefly and *Encarsia* populations shall be predicted by the basic model.

The interactions of the two insect species and its effect on the dynamics of the two species shall also be simulated.

The number and percentage of *Encarsia* wasps that stayed on the host plants during the first three days of introduction shall be estimated according to the experimental results of Xu et al.(in prep.).

(4) It is assumed that the *Encarsia* wasps feed on one whitefly larvae per day.

Host feeding can be observed on all stages of whitefly larvae. In this model, for simplicity, it is assumed that they feed proportionally on the whitefly larvae.

So, if the number of available host larvae is larger than the number of wasps staying on the host plants, each stage of whitefly larvae shall decrease a same proportion due to host-feeding.

If the number of wasps is larger than the number of available hosts, then all the host larvae shall be killed and the supplementary wasps which have no hosts to feed shall die of hunger (though some may feed on honey, we assume them to be unable to reproduce and thus diminished from the population counts).

(5) Parasitism is calculated according to the number of wasps

staying on the host-plants and the number of available host larvae. Each parasitized larvae shall contain a newly laid Encarsia egg, and they will develop as Encarsia immatures. After they develop and emerge, they will contribute again to the parasitism and biological control of the whiteflies.

The actual data and quantitative relationships shall not be given here.

III. Sensitivity Analysis of the Model

A parameter sensitivity analysis of the systems model is made. In this discrete model, sensitivity $S(t,\lambda)$ is expressed as;

$$S(t,\lambda) = \frac{n(t,\lambda+\Delta\lambda) - n(t,\lambda)}{n(t,\lambda)}$$

in which: $n(t,\lambda)$ is the population density growth under parameter λ at time t,

$n(t,\lambda+\Delta\lambda)$ is the population density growth with a turbulence of parameter $\Delta\lambda$.

The biological meaning of this is that we test the influence of a turbulence of +/-10% on each specific parameter. The end result is the relative bias of the final population density predicted. For example, if the sensitivity is 0.15, the relative bias of the final population is 15%.

In this analysis, a ±10% turbulence of each of the parameters is given sequentially and then compared.

The parameters compared were:
whitefly initial population density;
temperature (standard 20°C, biased to 18 or 22°C);
mortality rate of whiteflies;
whitefly fecundity;
developmental duration time of whiteflies;
timing of Encarsia introduction, 5 days earlier or later out of the 50 days predicted,
number of Encarsia wasps introduced.

These are all tested using tomato as host plants. The model predicts the population growth for 50 days. The final population densities were used for criterions of sensitivity. The whitefly population density as the major one and the Encarsia density as the minor one.

Additionally, under the same set of initial conditions, the population growth is also estimated by using different host-plant species.

The result is shown in Fig.1.

From Fig.1., it can be seen that:

(1). The quality of the host-plant, i.e., the host-plant species has the greatest influence on the population dynamics of the whiteflies. When the host plant is changed, the final population density estimated can differ from 0 to 102611. The sensitivity range from -1 to 3.6121.

The influence of host plant on Encarsia population developments are not so significant (sensitivity from -0.9926 to 0.1401). Nevertheless, it can be seen that the sensitivity has the same order E-C-T-P as with whiteflies. This may be due to the dependency of parasites to host population developments.

(2). The order of the sensitivity of the factors to whitefly developments are: duration time (-0.4202 to 0.6417); temperature (-0.3654 to -0.4516); fecundity (0.2721 to -0.2410), whitefly initial population density (0.1458 to -0.1514); timing of Encarsia introduction (0.1917 to - 0.0120); number of wasps introduced (-0.0476 to 0.0446); and finally, mortality (-0.0368 to 0.0382).

(3). The most sensitive factors influencing Encarsia population developments are: temperature (2.1932 to -0.4967), timing of Encarsia introduction (0.3843 to -0.0191) and initial whitefly population density (0.1338 to -0.0988).

(4). The result is no longer the same as those obtained by Liu & Xu (1982) for a single population. It is more complex with interspecific interactions. The result may also vary under different host-parasite densities and temporal combinations and under different environmental conditions.

IV. Ideas for Cooperation

The model for optimal biological control is for practice. The author highly appreciates cooperation with other researchers on the investigation of strategies for optimal control of whiteflies.

Data can be revised, the program can be rewritten to be adapted to different conditions and requirements. Other pests than whiteflies can also be considered. Chemicals and their effect can also be added into the program so that integrated management can be simulated.

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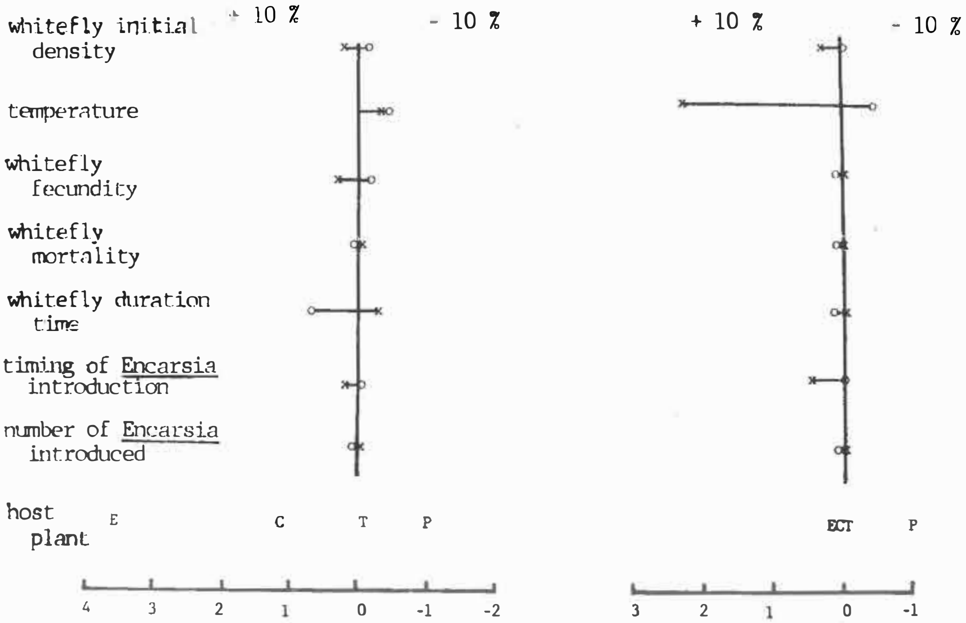

Fig.1. Sensitivity analysis of the systems model. ± 10 % turbulence of the parameters is given sequentially.
The notation is:
E: egg-plant; C: cucumber; T: tomato; P: paprika.
x : sensitivity under +10% turbulence of the parameter.
o : sensitivity under -10% turbulence of the parameter.

PARASITISM OF WHITEFLY BY ENCARSIA FORMOSA AT DIFFERENT RELEASE RATIO'S

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I. INTRODUCTION

Since the introduction of *Encarsia formosa* into greenhouses for control of the whitefly *Trialeurodes vaporariorum* (Westwood), extensive research programs have been operated to improve the biological control situation in some crops (van Lenteren et al. 1980).

The efficiency of this wasp in controlling whiteflies varies between host plants of different species and under different local conditions (e.g. whitefly density, temperature, size and climate conditions of the greenhouse ... etc.). Therefore, a number of studies have concentrated upon the distribution, migration and host-searching ability of the wasps.

There are several opinions concerning the migration ability of *E. formosa.* A study done in a large greenhouse (circa 6400 m^2, containing 18000 plants) indicated that the wasps have a good dispersal and searching capacity, the wasps covered distances of 10 m at least and they were able to find even a single host pupa on a plant that grew amidst many uninfested plants (Eggenkamp-Rotteveel Mansveld et al. 1982). These authors suggested that the differences in opinion concerning the migration ability might have resulted from studies done at very different host densities.

Hussey et al. (1976) considered host density as a factor affecting *Encarsia* dispersal. They wrote there are indications that parasites were more attracted to plants with large host populations, but due to the small number of adult parasites which colonized the plants, the results were inconclusive. Ledieu (1976) found that the response of the wasps to the hosts is density dependent. Circa 3 times more parasites were found in a high density sector compared to one with a lower density, which corresponds very closely to the ratio of infested plants in the respective sectors, namely 3:1 . But in this experiment the actual *Encarsia-Trialeurodes* ratio was not known, and the percentage parasitism was not investigated.

In this paper, we describe the results of a study mainly concerning the percentage parasitism of *Encarsia* under different host-parasite release ratio's, and the significance for biological control.

II. RESULTS

(1). Actual release ratio's.

The actual release ratio's were calculated from absolute counts in the greenhouse. The results are presented in Table 1.

Table 1. Release ratio of <u>Encarsia-Trialeurodes</u> in the three experiments.

Exp.	no. <u>Encarsia</u> dispersed in greenhouse	no. whitefly larvae (III-IV instar)	<u>E</u> : <u>T</u> release ratio
A	938	670	1.4 : 1
B	392	1093	0.36 : 1
C	2081	889	2.34 : 1

(2). Percentage of <u>Encarsia</u> found back on the host-plants.

Fig.1. illustrates the percentages of wasps that were found back on the plants against the initial number of wasps that dispersed in the greenhouse.

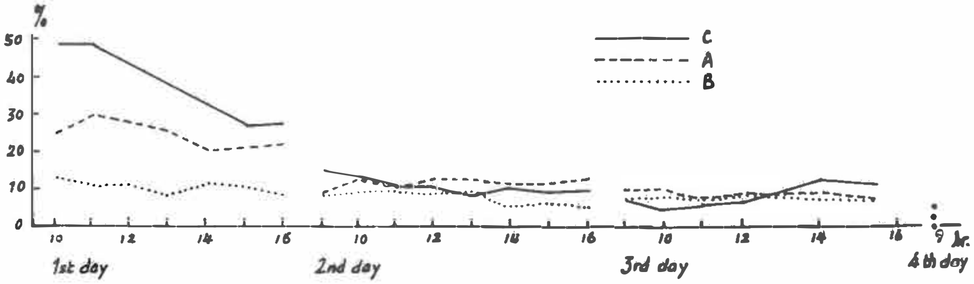

Fig.1. Percentage of <u>Encarsia</u> wasps present on the host plants in the course of time.

Significant differences between percentages wasps found back are only found for the first day of release. Curve C (max. 49.1%) is much higher than curve A (max. 30.3%) and curve A is much higher than B (max. 13.3%). From the second day onwards, the difference is no longer obvious. On the 2nd day, the percentages in Group A, B, and C are all around 10%. On the 3rd day, the percentages are about 5-10%. On the fourth day, the percentages are either zero or < 5%.

(3). Percentage parasitism

The percentage parasitism of whitefly (observed as black larvae) by *Encarsia* differs with the *E* : *T* release ratio. The result is illustrated in Table 2.

Table 2. Percentage parasitism of whitefly larvae by *Encarsia formosa*.

Exp.	*E*:*T* ratio	no. black larvae : no. initial larvae	percentage parasitism
B	0.36 : 1	420 / 1093	38.4
A	1.4 : 1	143 / 670	21.3
C	2.34 : 1	9 / 889	1.0

This result is at first sight quite unexpected. The higher the release ratio, the lower the percentage parasitism. Therefore, in the last experiment (Exp. C) a detailed analysis was made of the condition of the larvae. Out of the original 889 larvae, 701 were found back (79%), from which only nine were black parasitized larvae, while the other 692 larvae were dead ones, mainly caused by host-feeding. As each wasp will feed at least on one host per day, the result of many dead larvae can easily be explained: a total of 1022 wasps were found back on plants in experiment C. This indicates the extreme importance of host-feeding as a factor in the population dynamics and biological control of greenhouse whiteflies, especially where the release ratio is high.

When an abundance of hosts is provided, mortality due to host feeding is 17% compared to 83% caused by parasitization (van Lenteren et al. 1986).

III. Discussion

(1). In our experiments, the wasps flew to and settled on host plants in the furthest corner of the greenhouse within the first hour of release (24°C). This means that they can cover up to about 4 m within one hour. From these results, we may expect the *Encarsia* wasps to be able to cover many meters in commercial greenhouses due to their flight ability, and their long life-span.

(2). At the *Encarsia* - *Trialeurodes* release ratio's in the three experiments, we might suggest that host-feeding and parasitism has occurred mainly within the first few hours after release. The number of *Encarsia* released is more than enough to control whiteflies.

Let us use Exp.A (the medium release ratio) as an example.Out of the 938 wasps dispersed in the greenhouse, the maximum number of wasps recorded was 284 (30.3%). Hosts which has been fed upon, may be accepted for host-feeding at a successive visit of the same parasite or a conspecific, but 44.4% is rejected after contact (van Lenteren et al, 1980). Each parasite will feed on a host on average once a day. Let us just have an assumption that 50% of the wasps find new hosts. For this 142 larvae are needed. Then, 528 (670 - 142) larvae are left for parasitism (host-feeding and parasitism cannot occur on the same host, van Lenteren et al, 1980). The average number of eggs laid per female per day recorded (Christochowitz et al, 1981) at the nearest temperature region is 4.5 eggs at 23°C (van Lenteren & Woets, 1977), and 11.2 eggs under 22.5°C (Madueke, 1979). In this case, there are only 1.86 larvae left for each wasp. With their magnificent searching and moving ability, we can almost be sure that they can parasitize all the remaining larvae in just these few hours.

(3). The relationship between percentage parasitism and number of *E. formosa* present should be heavily stressed for its importance in biological control. As shown by our experiments, a higher release ratio does not always result in better biological control. The disadvantageous effects are : (i) most *Encarsia* wasps are wasted. (ii) a high proportion of host-feeding results in a decrease of the *Encarsia* population in later generations. Both effects result in ecological and economical inefficiency.

In sophisticated biological control the release ratio should be controlled so that only a small amount of whiteflies are being fed upon, a small number not attacked, and the majority of whitefly larvae are parasitized over a relatively long period (say, 1-2 weeks). Thus, (i) most whitefly larvae are killed, so that no economic damage occurs; (ii) a small amount of whiteflies is left to maintain the *Encarsia* population continuously, so that other immigrating whiteflies can be controlled. (iii) wasps will emerge over long periods of time.

We think that for achieving optimal biological control, it is adviceble to build mathematical models dealing with the *Encarsia* - *Trialeurodes* interaction to find out the optimal release ratio and timing of introduction under different initial whitefly population densities and environmental conditions. This is the main reason why mathematical models for whitefly biological control are constructed (e.g. Xu, also in this bulletin).

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POPULATION RESPONSES OF ENCARSIA FORMOSA TO THE GREENHOUSE WHITEFLY AND THEIR ROLE IN POPULATION DYNAMICS OF WHITEFLY-E. FORMOSA SYSTEM

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Summary

Population responses of *Encarsia formosa* to the greenhouse whitefly were studied in glasshouse experiments to examine their role in the population dynamics of whitefly-*E. formosa* system. Both responses of parasitization and host feeding by parasites to whitefly larvae showed Holling's type II responses. The number of parasitized per one parasite decreased at the higher density of parasites. The second instar larvae were more killed by host feeding than the older instars. The ratio of killed by host feeding to those by parasitization increased as the number of parasites increased. The results of experiments were fitted to the 'disc equation' by Holling(1959) and the parameters, the searching rate and the handling time were estimated. The searching rate and the upper limit of the number of killed per one parasite decreased with the increase in the number of parasites. The roles of the responses in the population dynamics of the whitefly-*E. formosa* system were discussed.

1.1 Introduction

It is well known that the greenhouse whitefly population in a greenhouse persists for several months at low density when *Encarsia formosa* is introduced (Burnett, 1964, 1967). The whitefly population is not only suppressed to low density but also is stabilized by the effects of *E. formosa.* These effects are caused by the mortality of whiteflies by *E. formosa* which are the results of population responses of *E. formosa.* In order to consider the strategy of the use of *E. formosa,* it will be essential to understand the population dynamics of the whitefly-*E. formosa* system. Population responses were investigated in glasshouse experiments to examine their role in the population dynamics.

1.2 Functional response of E. formosa on whitefly populations

Functional response of *E. formosa* on whitefly populations was studied in glasshouse experiments. Whitefly adults were released for oviposition on potted tomato plants(about 0.5 m in height), then the hatched larvae were reared on them until they reached a certain instar. After that, various numbers of *E. formosa* adults were released and the numbers of parasitized or fed by parasites were counted later. Both the functional responses of parasitism and host feeding showed satuated type responses or Holling's type II responses(Fig. 1). The numbers attacked by a parasite decreased with the increase of the number of parasites. The second instar larvae were more killed by host feeding than the older instars. The ratio of killed by host feeding to those by parasitization increased remarkably as the increase of the number of parasites. The older instar larvae were almost killed by parasitization irrespective of the number of parasites. The difference of temperature conditions did not significantly affected on the responses.

1.3 The model to describe the functional response

Adults of Encarsia formosa show parasitization and host feeding responses to whitefly larvae. They can discriminate the healthy and the parasitized host. Considering these behavioural features, the model to describe the functional response of E. formosa was developed based on the 'disc equation'(Holling, 1959) and the 'random predator equation'(Rogers, 1972).

We first assume that the ratio of the parasitization to the host feeding in the attack by a parasite is constant, $k/(1-k)$. Let N be the number of hosts, P the number of parasites. Assuming that an unit time interval is short enough that the host numbers do not vary significantly, the number of hosts parasitized and fed, N_1 and N_2 during this period are

$$N_1 = \frac{kaPN}{1+[kh_1+(1-k)h_2]aN}$$

$$N_2 = \frac{(1-k)aPN}{1+[kh_1+(1-k)h_2]aN}$$

where a is the search rate and h_1 and h_2 are the handling time for parasitization and for host feeding, respectively. The total number of attacked hosts N_a is

$$N_a = N_1 + N_2 = \frac{aPN}{1+[kh_1+(1-k)h_2]aN}$$

or

$$N_a = \frac{aPN}{1+ahN}$$

where $h = kh_1 +(1-k)h_2$.
This equation is the 'disc equation' and h is the weighed average of the handling time for parasitization and for host feeding. We can estimate the k value from the relationship:

$$N_2 = (1/k-1)N_1$$

by the method of least squares. As the 'disc equation' indicates the instantaneous rate of attack, the 'random predator equation' is better to describe the functional response. The 'random predator equation' for the total response is

$$N_a = N[1-\exp(-a(P-hN_a)].$$

N_1 and N_2 are easily obtained by

$$N_1 = kN_a,\ N_2= (1-k)N_a$$

The estimation of the parameters of the 'random predator equation' was not suuessful by the method of Rogers(1972). The 'disc equation' was used to describe the relation between N and N_a . Table 1 shows the estimated parameters of the equation under different conditions. The estimated curves are shown in Fig. 1. The search rate a and k decreased while the handling time h increased with the increase of the number of parasites. The reciprocal of h indicates the upper limit of N_a/P. Therefore, a parasite reduces its searching efficiency and its potential attacking ability and tend to feed hosts at the higher density of parasites.

1.4 Survival of whitefly populations exposed to the attack of Encarsia formosa populations of different densities

The survival of whitefly populations was studied in a glasshouse experiment, under the exposure to the attack of Encarsia formosa. 1, 5 and 30 adults were released on potted tomato plants each on which about 50 second instar larvae existed. The parasites were renewed every other day and the experiments were continued for 10 days. Fig. 2 shows the changes of the survival rates and the mortality rates by parasitization and host feeding. The higher mortality by host feeding and the lower mortality by parasitization were observed with the increase of the number of parasites.

1.5 Suggestions for the population dynamics of whitefly-E. formosa system

Holling's type II response is thought not to be regulatory response for the population dynamics of the system because of the inverse density dependence on the host density. The reduction of the searching efficiency with the increase of the number of parasites which is often called 'mutual interference' has stabilizing effects on host-parasite populations(Hassell, 1978). The higher mortality of larvae by host feeding at the higher density of parasites may also play an important role in the population dynamics.

1.6 Future research

The results of this study were very suggestive for understanding the population dynamics of whitefly-*E. formosa* system. But the mechanism of the complicated dynamic system will only be clarified by the modelling approach. Both simulation studies and thoretical studies by analytical models are progressed.

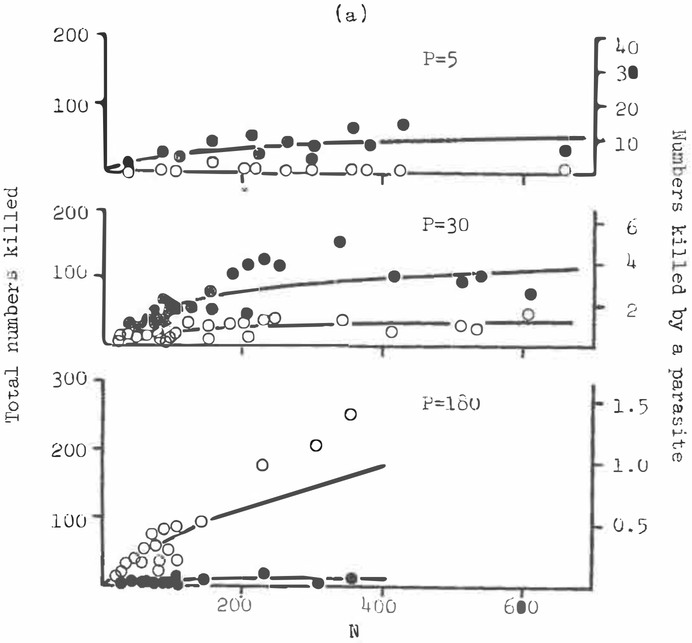

Fig. 1

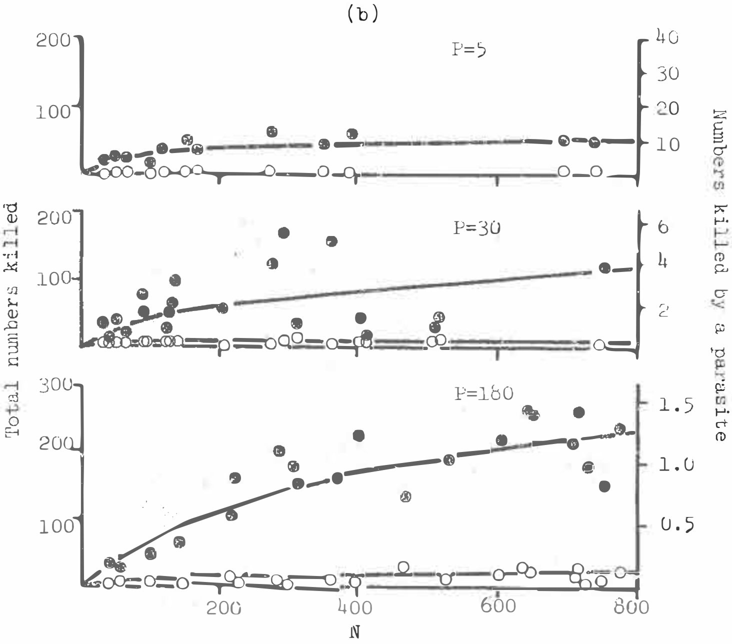

Fig. 1 Functional responses of different numbers of *E. formosa* (P) to the numbers per plant (N) of the second instar (a) and the third and the early fourth instar (b) of whitefly larvae. Closed and open circles indicate the numbers killed by parasitization and host feeding, respectively. The curves are drawn from the 'disc equation'.

Table 1 Parameters of the 'disc equation' and k values under different conditions of the parasite density and the temperature.

Larval instar	No. parasites	Day 30°C, night 20°C			Day 25°C, night 10°C		
		a	h	k	a	h	k
2nd	180	0.00497	0.4860	0.0603	0.00575	0.1009	0.3884
	30	0.04087	0.1697	0.7485	0.02418	0.0909	0.6806
	5	0.07225	0.0619	0.9328	0.07531	0.2631	0.8480
3rd and early 4th	180	0.00474	0.4694	0.9095	0.00530	0.2925	0.8214
	30	0.01552	0.1903	0.9563	0.01639	0.2519	0.8876
	5	0.10443	0.0915	0.9838	0.03614	0.0705	0.9747
later 4th	180	0.00459	0.0695	0.9171	0.00465	0.6277	0.7328
	30	0.02571	0.1577	0.9079	0.00432	0.3729	0.8582
	5	0.04248	0.0580	0.9033	0.14698	0.0401	0.8537

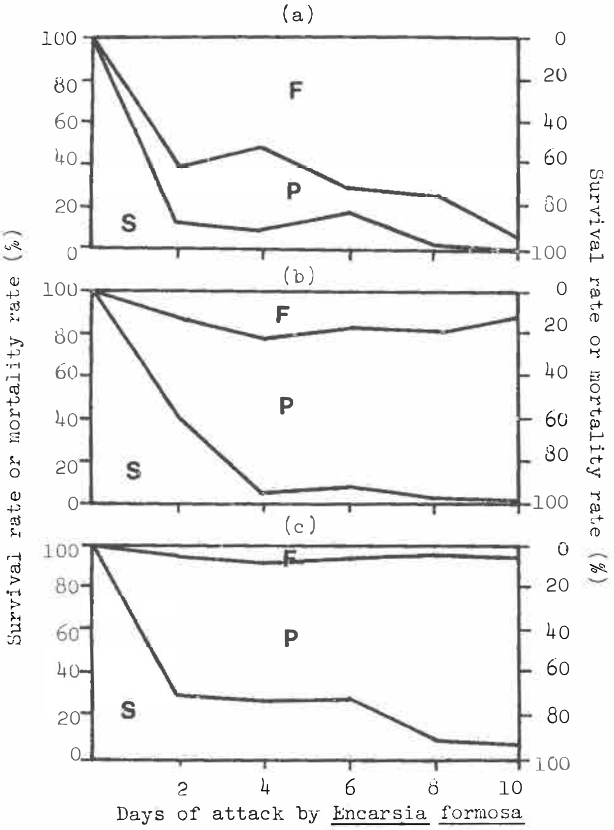

Fig. 2 Survival and mortality of whitefly larval population attacked by *Encarsia formosa* of different densities, 30(a), 5(b) and 1(c) per plant. F and P mean mortality rates by host feeding and by parasitization, respectively. S means survival rates.

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QUANTITATIVE MONITORING TECHNIQUES FOR THE GREENHOUSE WHITEFLY

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Summary

Quantitative monitoring techniques for detecting the early infestation of the greenhouse whitefly are needed to determine the critical timing of control. Three-stage sampling and presence-absence sampling methods were applied for estimating the density of whiteflies on tomatoes based on the analyses of the spatial distribution of whitefly populations. By using the leaflet as a sampling unit, an efficient three-stage sampling plan was proposed. The relationship between the mean number per plant and the ratio of plants infested, which gave the basis of the presence-absence sampling, was formulated by the equation of Gerrard and Chiang(1970). Trapping experiments of whitefly adults were conducted in a glasshouse using yellow sticky traps. From the results of the experiments, a method for determining the timing of the introduction of *Encarsia formosa* was proposed. Presence-absence sampling and the trapping method were considered useful for monitoring purposes.

1.1 Introduction

Early control is essential to achieve effective control of the greenhouse whitefly. Introduction of *Encarsia formosa* at early stage of infestation by whiteflies is stressed(Foster and Kelly, 1978). In case of chemical control, early treatment is strongly recommended(Nakazawa et al., 1979). If quantitative monitoring techniques to detect whiteflies in their early infestation are available, the critical timing of control could be reasonably determined. Development of monitoring techniques will also provide the basis of integrated pest management. From this point of view, some kinds of monitoring techniques for the greenhouse whitefly were developed and evaluated.

1.2 Three-stage sampling

counting of all individuals on a whole plant is a labour-consuming work. By using the smaller sampling unit, the more efficient sampling plan can be developed. A three-stage sampling plan for estimating the density of whiteflies on tomatoes was developed, where a leaflet was used as the basic sampling unit. We assume that whole area consists of L plants, each having K leaves, and a leaf can be divided into Q leaflets. On sampling, we first select ℓ plants as the primary sampling units(PSU), then we select k leaves as the secondary sampling units(SSU) from each PSU, and finally we select q leaflets as the tertiary sampling units(TSU) from each SSU(Fig. 1). Kuno(1976) developed a three-stage sampling method on the assumption that the linear $\overset{*}{m}$-m relationship with a common intercept α, $\overset{*}{m} = \alpha+\beta_1 m$, $\overset{*}{m}_i = \alpha+\beta_2 m_i$, and $\overset{*}{m}_{ij} = \alpha+\beta_3 m_{ij}$ hold for the distribution of individuals per TSU over the whole area, that within PSU and that within SSU, respectively. In this case, the estimate of mean density is

$$m = \bar{x} = \frac{1}{\ell kq} \sum_{i=1}^{l} \sum_{j=1}^{k} \sum_{k=1}^{q} x_{ijk}.$$

The necessary number ℓ of PSU's to be sampled when both k and q is fixed is

$$\ell = \left[\frac{\beta_1-\beta_2}{\beta_2} + \frac{1}{k_0}\left(1- \frac{k_0}{K}\right)\left(\frac{\beta_1-\beta_3}{\beta_3} - \frac{\beta_1-\beta_2}{\beta_2}\right) + \frac{1}{k_0 q_0}\left(1- \frac{q_0}{Q}\right)\left\{\frac{\alpha+1}{m} + \frac{\beta_1(\beta_3-1)}{\beta_3}\right\}\right] \Big/ \left(D_0^2 + \frac{1}{L}\,\frac{\beta_1-\beta_2}{\beta_2}\right)$$

where k_0 and q_0 are the fixed values of k and q and D_0 is a predetermined precision level in terms of D = d/m or standard error relative to the mean. Kuno (1976) also provided a method to calculate the distribution parameters(i.e. α, β_1, β_2, β_3) from the obtained data. Fig. 2 shows the m - ℓ relationship for D_0 = 0.2 for all the developmental stages.

1.3 Presence-absence sampling

The presence-absence sampling or the binomial sampling is a simple and very convenient method to estimate the density of a population. Workers are only required to record the presence(with one or more) or the absence(with none) of the target pest in each sample. The density can be estimated from the relationship between the mean density and the ratio of infested samples. Some equations have been proposed to describe this relationship. One of the commonly used is the equation by Gerrard and Chiang(1970). The mean density m is expressed as a function of proportion infested, p having two parameters, c and d

$$m = c[-\ln(1 - p)]^d .$$

If both sides are transformed by logarithm, it becomes

$$\log m = \log c + d \log[-\ln(1 - p)].$$

If the relationship of log m and log[-ln(1 - p)] is expressed by a linear regression, the coefficient and the intercept indicates d and log c, respectively. Kuno(personal communication) presented a equation for determining the sample size at a constant precision. The sample mean has the variance

$$V(\hat{m}) = \frac{\hat{p}}{q(1 - \hat{p})} [cd\{-\ln(1 - \hat{p})\}^{d-1}]^2$$

where q is the number of samples used for the calculation of $\hat{p}$. And the necessary sample size n is

$$n = \frac{q \times V(\hat{m})}{m^2 \times D_0^2}$$

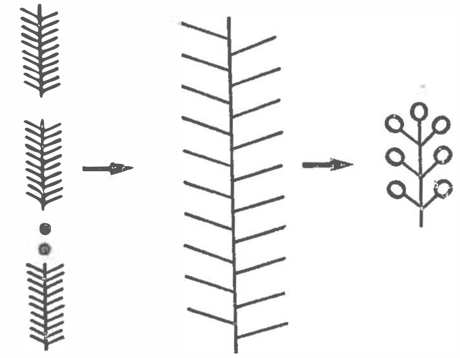
where D_0 is a precion level in terms of $D = \sqrt{V(m)}/m$. Fig. 3 shows the relationship between the ratio of plants infested and the number of whitefly adults per plant. The line in the figure shows the relationship between m and p expected from the equation of Gerrard and Chiang(1970).

1.4 Use of yellow sticky traps

The preference of adults of the greenhouse whitefly for yellow colour was shown by Lloyd(1921). Greenhouse experiments were conducted to develop monitoring methods by using yellow sticky traps. One hundred potted tomato plants of about 0.4 m in height were arranged in a glasshouse at intervals of 0.5 m to give a 10x10 arrangement(Fig. 4). After the release of whitefly adults, a yellow sticky ribbon(4x80cm) was suspended at the centre of the plants, then the number of adults caught was counted daily for a week(Fig. 5). Effects of initial density and distribution of adults and temperature condition in the glasshouse on trapping patterns were studied by the experiments. Initial distribution of adults did not have significant effects on trapping efficiency. The higher density and the lower temperature reduced the trapping efficiency. On the basis of the results of the experiments, a scheme of introduction of Encarsia formosa was proposed where the yellow sticky ribbon is used for monitoring whiteflies. Yellow sticky traps are suspended every 100 plants just after planting. If 10-20 adults(above 25°C) or 1-5(below 20°C) are caught in a week, 100 parasitized pupae are introduced per 100 plants, followed by the second and the third introduction of the same number at fortnight intervals.

1.5 Future prospect

Three kinds of monitoring methods were proposed here. The three-stage sampling plan is a precise and a labour-saving method, but is a complicated one for practical purposes. On the other hand, the presence-absence sampling and the use of yellow sticky traps could be recommended for monitoring in IPM. Use of yellow sticky traps is very promising because of the simplicity and the high effectiveness in detecting whiteflies of low density. Reliable monitoring methods could be empirically developed based on the results of trapping experiments under different conditions as described here. Control experiments of whiteflies by Encarsia formosa introduced according to the scheme proposed here were successful(Yano, 1987 in press), which demonstrated the usefulness of the introduction scheme.



Plants

A plant having 20 leaves

A leaf having 7 leaflets

Fig. 1 Schematic representation of the various units in three-stage sampling of tomato plants.

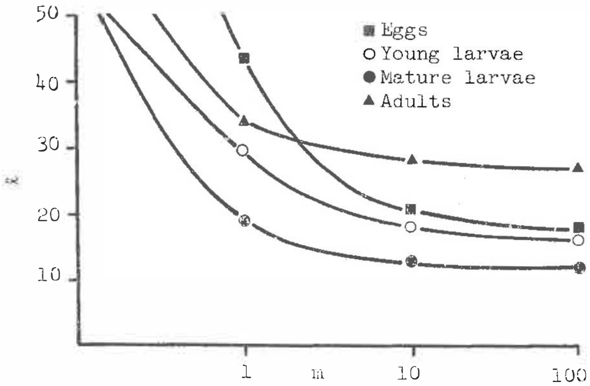


Fig. 2 The necessary number of plants to be sampled (ℓ) in three-stage sampling ($D_0=0.2$, $k_0=3$, $q_0=1$, $K=16$, $Q=7$, $L=40$).

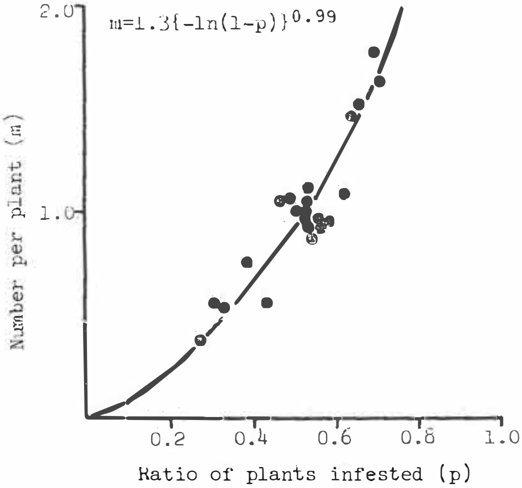


Fig. 3 Estimation of number per plant by ratio of plants infested. The curve shows the expected from the equation of Gerrard and Chiang (1970).

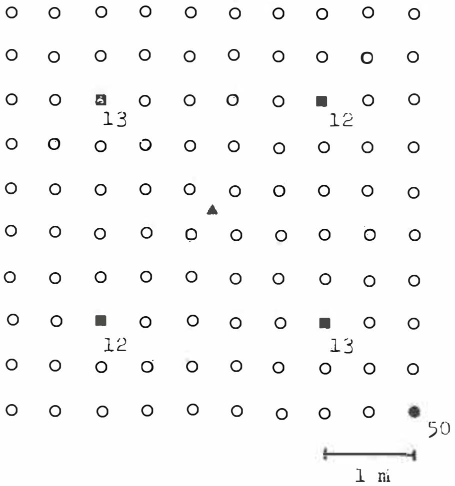


Fig. 4 Arrangements of tomato plants, release points of whitefly adults and a yellow sticky ribbon. Numbers indicate the numbers of released adults.

○ : tomato plants
▲ : a yellow sticky ribbon
● : the release point from which 50 adults were released
■ : the release points from each of which 12 or 13 adults were released

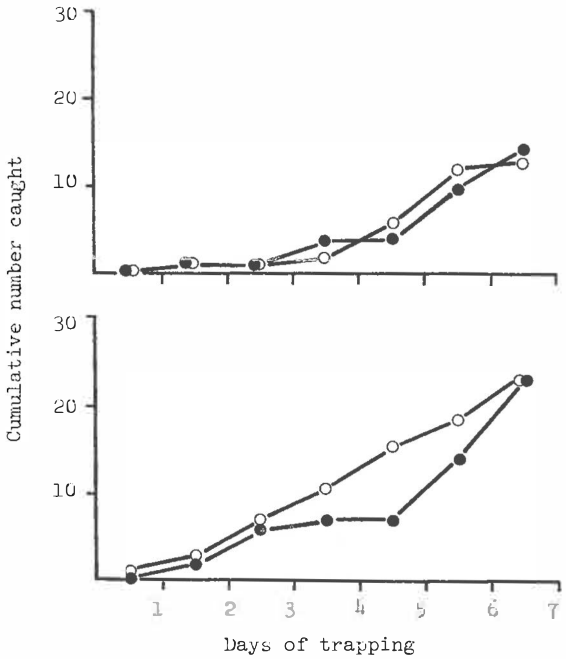


Fig. 5 Trapping experiments by yellow sticky ribbons. The upper and the lower figure indicate the results of experiments where 50 adults were released from one point and from four points, repectively. Open and closed circles indicate the results of two replications.

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