IOBC / WPRS
Working Group
“Integrated Control in Protected Crops, Temperate Climate”

OILB / SROP
Groupe de Travail “Lutte Intégrée en Cultures Protégées, Climat Tempéré”

Proceedings of the meeting

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Annie Enkegaard

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Preface

This Bulletin contains the preceedings of the triennial meeting of the IOBC/wprs Working Group “Integrated Control in Protected Crops, Temperate Climate” (the 13th full meeting) held in Sint Michielsgestel, The Netherlands, 21-25 April, 2008.

The Bulletin contains 64 contributions authored by ca. 125 people from more than 25 countries/states on numerous aspects of biological and integrated pest management in protected crops. I welcome all the contributions including the contributions from the students who participated in the student competition.

The local organisation of the meeting was excellently handled by Gerben Messelink, Pierre Ramakers, Marieke van der Staaij, Anton van der Linden (Wageningen UR Greenhouse Horticulture) and Jeroen van Schelt (Koppert Biological Systems). I thank the team for their hard work and their enthusiasm aimed at scientifically and socially successful meeting.

Finally, I am indebted to Sonja Graugaard, Aarhus University, Faculty of Agricultural Sciences, Department of Integrated Pest Management, for her considerable efforts in correcting and adjusting the manuscripts and compiling this Bulletin.

This is my final year as convenor of our working group and I would like to take the opportunity to thank all who has supported me during my term of office both at and between meetings. It has been a privilege and a pleasure to undertake this task. I convey my best wishes to the new convenor and my best hopes for the Working Group in the future.

Annie Enkegaard, Working Group Convenor
30th January 2008
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Association of fungus gnats with oomycetal plant pathogens

Sarah Arnold¹, Stephen Wraight², Eric Nelson³, John Sanderson¹
¹Dept. of Entomology, Cornell University, Ithaca, NY, USA, 14853-0901, E-mail: sea35@cornell.edu; ²USDA-ARS, US Plant, Soil and Nutrition Laboratory, Ithaca, NY, USA, 14853-2901; ³Dept. of Plant Pathology, Cornell University, Ithaca, NY, USA, 14853-0901

Abstract: Dark-winged fungus gnats in the genus Bradysia (Diptera: Sciaridae) are especially abundant in greenhouse plant production. Although it is thought adult fungus gnats generally do not feed in the greenhouse setting, sciarid larvae feed mainly on microorganisms in the soil, including various Oomycetes, Ascomycetes, Basidiomycetes, and Myxomycetes. However, larvae of several species have also been observed consuming root, stem, and sometimes leaf tissue of apparently healthy vascular plants in greenhouses, and have been implicated in the transmission of certain root pathogens. In this laboratory study, Bradysia impatiens larvae chose to associate with oomycetal cultures of Pythium aphanidermatum, Pythium ultimum, or Pythium irregulare more frequently than the medium on which each of these pathogens was grown.

Key words: fungus gnat, Pythium, plant pathogen

Introduction

The role of insects in the transmission of plant pathogens has been documented for more than a century. As early as 1891, M.B. Waite demonstrated that honeybees (Apis spp.) play a major role in the movement of Erwinia amylovora, a bacterial pathogen that causes fire blight of apple and pear trees (Waite, 1891). In the greenhouse setting, flower crop selection and disease and insect management priorities have been greatly influenced by the fact that certain aphids (Yano, 2006), thrips, and whiteflies can transmit plant viruses. However, other insects, sometimes considered nuisances, have been implicated in the spread of soilborne plant pathogens in greenhouses. One key example of such insect pests is the fungus gnat, Bradysia spp. Understanding the interactions of these insects with soilborne pathogens is very important, as the development of more appropriate disease and insect management strategies may be warranted, depending on the nature of vector-pathogen relationships (El-Hamalawi, 2007).

Studies have pointed to a connection between plant pathogens and greenhouse-inhabiting fungus gnats. Transmission of soilborne pathogens by fungus gnats has been documented for several species of pathogens (Kalb & Millar, 1986; Gillespie & Menzies, 1993; Harris, 1995). However, little research has been done on the association of fungus gnats with Pythium spp. in greenhouse floriculture, though Pythium spp. are among the most serious root pathogens.

A fungal diet is essential for Bradysia spp. found in greenhouse crops. Bradysia impatiens larvae develop more rapidly and exhibit greater survivorship when reared on fungal diets of Alternaria tenuis or brewer’s yeast (Saccharomyces cerevisiae) than on non-fungal diets of lima bean agar, potato dextrose agar, or agar-agar (Kennedy, 1974). Also, Kennedy (1976) observed B. impatiens larval survival to be reduced when fungal abundance (brewer’s yeast) was low which, subsequently, resulted in reduced root damage. Total larval development from egg to adult was also significantly shorter in pots containing fungus than in pots without fungus. High mortality of first and second instars in pots with plants but no
fungus indicated that a fungal food source is necessary for these age classes. Furthermore, *B. impatiens* females prefer oviposition sites that contain some form of fungus. In an arena of potted plants, with and without fungus (brewer’s yeast or decaying leaves), significantly more eggs were laid in pots that contained fungus compared to those that did not (Kennedy, 1976).

A related species of fungus gnat, *B. coprophila*, failed to survive on fungus-free plant tissue, but exhibited high survivorship when placed on plants inoculated with *Botrytis porri*, *Rhizoctonia solani*, or *Sclerotinia minor*. Larvae placed on cultures of these fungi developed into adults that were able to successfully reproduce. However, when the larvae were placed on cultures of the fungus *Trichoderma viride*, a fungal antagonist, they exhibited poor survivorship and no later reproduction (Anas & Reeleder, 1988).

Although Kennedy (1976) described adult fungus gnats as generally aphagous in the greenhouse setting, larval fungus gnats actively feed and can cause direct damage to the root systems of a variety of plants. In 1901, Chittenden first reported the pestiferous nature of larval fungus gnats in greenhouse production of cucumbers (Chittenden, 1901).

As part of a study of the interactions among *B. impatiens*, *Pythium* spp., and bedding and potted floral crops, the goal of the present study was to determine whether *B. impatiens* larvae prefer to associate with particular oomycete plant pathogens that can cause significant crop losses under intense cultural practices in greenhouse production; namely, *P. aphanidermatum*, *P. ultimum*, and *P. irregulare* were examined.

### Materials and methods

#### Insect rearing

*B. impatiens* adults and larvae were reared in plastic containers (9.8 cm diameter × 6.2 cm depth) with lids (10.2 cm diameter) bearing holes (5.5 cm diameter) lined with nylon mesh (95 μm) for ventilation. Fifty fungus gnat adults (predominately females) were placed in each container and provided with approximately 40 grams of growing medium (Premier Pro-Mix®, Quakertown, PA) moistened with tap water and approximately 10 grams of ground pinto beans (Goya® Foods, Inc., Secaucus, NJ). Colony containers were maintained in an incubator at 27°C and 14h: 10h L:D. To obtain an even aged cohort for use in bioassays, approximately 200 adult fungus gnats were released from colony containers into a 45 cm × 45 cm × 45.5 cm cage in the laboratory at ambient temperature and allowed to oviposit on 100 mm diameter Petri dishes (Becton Dickinson Labware, Franklin Lakes, NJ) that contained moistened cotton covered with a piece of black filter paper with a thin layer of ground pinto beans spread on it. After 24 hours, Petri dishes were removed and maintained in the same incubator as the colony containers until the desired life stage was attained for bioassays. Additional water and pinto beans were added to the Petri dishes as needed.

#### Pathogen maintenance

*P. aphanidermatum, P. ultimum*, and *P. irregulare* were grown on V8 agar. *P. aphanidermatum* was maintained in an incubator at 27°C and 24 h D, while the other two species were maintained in an incubator at 24°C and 24 h D. One-week-old culture plates were used in this study.

#### Bioassay protocol

The following bioassay was conducted in 100 mm diameter Petri dishes (Becton Dickinson Laboratory, Franklin Lakes, NJ) containing one piece of 90 mm diameter white filter paper (Whatman® No. 1, Maidstone, UK) moistened with 1.5 ml of sterilized water. One size 8 core (12 mm diameter) each of *P. aphanidermatum, P. ultimum, P. irregulare*, and V8 agar alone
was placed equidistantly around the circumference of a Petri dish. One third-instar fungus gnat larva was placed in the centre of the Petri dish, and the location of the fungus gnat larva relative to the four agar cores was noted after 30 minutes. Larvae that were touching a given core were scored as being associated with that core. Two assays were conducted with twenty-four and twenty-three replicates, respectively. Data of the two replicates were pooled for analysis. Replicates in which larvae did not make any choice were not included in the statistical analyses.

Results and discussion

This study reveals that fungus gnat larvae tend to associate more with *Pythium* spp. than V8 agar alone (Table 1). No significant difference was detected in larval association among the three *Pythium* species. Though larvae could be clearly associated with a *Pythium* core after only 30 minutes, it is not known whether the association with a given *Pythium* species was due to attraction or arrestment.

The findings from this study are notable since they are in line with prior research indicating *B. impatiens* requires a fungal food source to develop rapidly and exhibit high survivorship (Kennedy, 1974).

Table 1. Number of third-instar fungus gnats on each medium type after 30-minute assays.

<table>
<thead>
<tr>
<th>Larval choice</th>
<th># Larvae(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pythium aphanidermatum</em></td>
<td>17 a</td>
</tr>
<tr>
<td><em>Pythium ultimum</em></td>
<td>8 a</td>
</tr>
<tr>
<td><em>Pythium irregulare</em></td>
<td>14 a</td>
</tr>
<tr>
<td>V8 agar</td>
<td>0 b</td>
</tr>
<tr>
<td>No choice</td>
<td>8</td>
</tr>
</tbody>
</table>

\(^a\)Means followed by the same letter within a column are not significantly different (Pearson’s chi-square test, \(P < 0.01\)).

Although further replication of experiments is needed, it is clear from past research that *B. impatiens* larval survival is increased when fungal abundance (brewer’s yeast) is high which, subsequently, results in increased root damage (Kennedy, 1976). Many questions still remain unanswered involving the interactions of insects with plant pathogens in greenhouses. Perhaps feeding activities of fungus gnat larvae cause infection courts for *Pythium* spp., as is the case with *Fusarium* spp. on alfalfa and red clover (Leath & Newton, 1969). Additionally, germination of *P. aphanidermatum* oospores has been shown to significantly increase by passage through live water snails compared to germination with no processing by an invertebrate. The passage of oospores through fungus gnats may increase the germination rate of oomycete propagules.

Integrated strategies involving cultural, biological, and chemical control of insects may be warranted to manage soilborne plant pathogens.

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Developments in greenhouse horticultural production systems

J.C. (Sjaak) Bakker
Wageningen UR Glastuinbouw, Violierenweg 1, 2665 MV Bleiswijk, Post Box 20, 2665 ZG Bleiswijk, The Netherlands, E-mail: sjaak.bakker@wur.nl

Abstract: A short overview of recent developments in Dutch horticultural industry is presented focussing on four topics: 1) optimal use of the greenhouse area, 2) maximal utilisation of light, 3) reduction of energy use, and 4) complete control of the greenhouse environment.

Key words: innovations, mobile cropping systems, energy conserving greenhouses, controlled environment greenhouses

Introduction

Greenhouse horticultural production systems worldwide are constantly subject to innovations aimed at increasing both yield and quality, reducing the major cost factors and meeting market demands and governmental regulations. The focus is on expanding the growing season towards year round production and on compensating for factors formerly restricting the production (e.g. low natural light).

In Dutch greenhouse horticulture, the overall trend is an annual increase of the economic value with about 10%, achieved at an almost stable total greenhouse area of 10,500 ha with fewer but much larger operational units. Newly built greenhouses for tomato production, for example, often occupy 8 to 10 ha with a maximum of 35 ha. Individual companies may own different production sites, including some abroad, with areas totalling up to 100 ha. New greenhouse areas are restricted to a limited number of appointed locations, while current greenhouse areas are under pressure by expanding nearby cities. The overall effect is a strong increase in land prices (now between 75 and 100 Euro/m²). Production is much more market driven (delivery on demand) than before, so production planning and quality control during the production phase have become more important. While production is taking place in ever larger units, new technologies enable fine-tuning of production control within these units: from entire greenhouse compartments to clusters of plants, rows or, in the future, even individual plants. Recent innovations focus on labour and energy costs, as they are by far the most important cost factors. In this paper, a short overview of recent developments in Dutch horticultural industry is presented, focusing on 4 major topics:

Optimal use of the greenhouse area

With the increasing land prices and greenhouse building costs, maximizing the net productive area has become a major issue. Overhead robot systems for pot plants and transplant production enable almost 100% floor utilization. Mobile benches or gutters for pot plants and cut flowers like gerbera, rose and chrysanthemum (Mobyflowers) eliminate the need for work aisles. In the Walking Plant System even individual plants are moving.

Mobile production systems for (fruit) vegetables have been the subject of research for decades, either combined with NFT systems or with single truss harvesting for tomato (e.g.
Giacomelli et al., 1994). Sweet pepper was tested in the Walking Plant System. Although a yield up to 47 kg per m\(^2\) was reached, so far for vegetable production the operational costs of mobile systems are too high to make commercial application feasible.

The second important advantage of mobile production units is centralised handling, reducing the manual labour required. In such a setting, investment costs for advanced equipment (harvest robots, pesticide application cabins) are more likely to be recovered. The first prototype of a harvesting robot was developed for cucumbers (van Henten et al., 2002) followed by a commercial rose harvesting robot (Jagers op Akkerhuis, 2003) introduced at the Hortifair in 2007.

Another way to optimally use the greenhouse is by multiple use of space. A two layer system, combining plant production on movable benches in the top of the greenhouse with potting, sorting, logistics, handling etc. underneath, is being used at several large production units of leading companies like Bunnik Plants (pot plants) and Sion (Cymbidium). In areas with a high greenhouse density, basins for temporary storage of rain water have become too expensive due to the high land prices. Several solutions for storing water under the greenhouse are available: the ‘Watershell®’ system with top floor and the ‘Klimrek’ storage system with a floating floor (Visser, 2007). A further step is a floating greenhouse (Bakker et al., 2005), the first model of which was constructed near the Flower Auction in Naaldwijk.

Maximal use of natural and additional light

Improving the greenhouse light transmission not only has a positive effect on photosynthesis, it also reduces the additional heating power required (see next paragraph) and thus improves energy efficiency (Elings et al., 2005). Interception of light by the greenhouse construction has already been minimised by integration of construction parts, minimised dimensions of gutters, use of wide (>1.7 m) glass panels and white coated frames (Janssen & ‘t Hart, 2006). Within the limitations of current material technology and international construction norms, further improvements along these lines (e.g. by using trellis type columns) are expected to bring only marginal benefits (2%). Therefore, any significant increase in light transmission primarily depends on innovations in the transparent roof materials.

For optimal use of solar radiation, the transmission for not only photosynthetic active radiation but also infra red radiation is to be considered (Hemming et al., 2004). For the winter period, one should aim at materials which combine a high transmission for visible light, a low transmission for IR radiation and a high insulation value. IR transmission is too high in many film materials except for the recently introduced ETFE membrane (Hemming, 2005; Waaijenberg et al., 2005). During the last decades, several anti-reflex coatings have been introduced which increase light transmission by 5 to 6% (Hemming et al., 2006a). A recent innovation in this field is modifying the surface structure (e.g. micro-V). It may first be implemented on solar panels, but is also a promising technology for greenhouse covers (Sonneveld & Swinkels, 2005a). Recent studies show that diffuse light is able to penetrate deeper into a plant canopy than direct light. At equal overall transmission, crop production could be improved with covering materials which diffuse the incoming light (Jongschaap et al., 2006; Hemming et al., 2006b).

In the attempt to realise year round production, the application of artificial light has become common practice. In northern regions very high levels are used: up to 100 Wm\(^{-2}\) in The Netherlands, and even over 200 Wm\(^{-2}\) in Finland (Olofsson et al., 2006). The application of artificial light started in floriculture crops like chrysanthemum and rose, but during the last decade it has also been introduced in fruit vegetables. Due to increasing social pressure, today artificial light can only be applied if the light emission is reduced by 95%. For the future, the
reduction target is even set at 100%. New LED based systems are being introduced to increase the energy efficiency of artificial light, apply specific wavelengths and at the same time reduce the additional heat input into the greenhouse, enabling easier application of light emission reducing screens.

Reduction of energy use

The balance between additional profit and costs of energy input is, of course, location specific. For Europe it varies between 500 and 1,900 MJm⁻² per year (Bakker et al., 2007). One might expect that in southern countries the economic incentive to save on energy use is low compared to northern regions. It turns out, however, that in relative terms the importance of energy as a cost factor is similar. Both in Italy and France (Boulard, 2001; de Pascale & Maggio, 2004) and in the northern regions (van der Knijff et al., 2004) the energy use for vegetable growing accounts for 20 to 30% of the total production costs.

With the recently more pronounced interest in global warming and climate change, the use of fossil fuel is on the political agenda again. As a result, new goals have been set for energy reduction: the Dutch Horticultural Industry aims at -30% CO₂ emission in 2020 compared to 1990. Basically, there are two ways to reduce the absolute (fossil) energy use and related CO₂ emission: efficient technology for converting the source energy into a usable form (heat, cold, light) and reduction of the losses to the environment. The first way hardly affects the internal growing conditions. Therefore, in the framework of this conference it is not dealt with further.

The development of energy efficient systems is an optimisation process and the result of step by step improvements and adaptations of the production system, to meet the requirements of the given constraints and local conditions. In general, the objectives stated by de Pascale and Maggio (2004) for Mediterranean areas also apply to other regions: maximise the radiation quantity (from either natural or artificial light) during fall and winter and minimise the energy losses. To achieve this, commercial greenhouses already use (improved) thermal screens, covering materials and model based climate control systems.

Thermal screens

A thermal screen forms an additional barrier between the greenhouse environment and its surroundings and reduces both convection and ventilation loss. Mobile screens have less impact on the light transmission, compared to fixed screens or double roofs. In The Netherlands, 79% of the greenhouse area equipped with thermal screens (van der Knijff et al., 2004). Theoretically, fixed screens can reduce energy use by more than 35% (Bakker & van Holsteijn, 1995). In commercial practice, mobile screens are closed only a part of the time (Dieleman & Kempkes, 2006). Depending on the (humidity and light related) set points for closing, actual energy savings are restricted to 20%. Innovations in the field of thermal screens are related to its operational control, balancing energetic effects against production (Dieleman & Kempkes, 2006).

Covering materials

Increasing the insulation value of the greenhouse roof has a major impact on the energy consumption. Most fixed insulating covers, however, reduce light transmission and increase humidity. Developing materials which combine high insulation values with high light transmission is one of the most challenging issues. The Lexan® ZigZag™ greenhouse roof is an example of such a material. Compared to single glass, energy saving can be 45% momentary and 20 to 25% year round (Sonneveld & Swinkels, 2005b). Practical application
is limited due to additional costs for the greenhouse construction compared to the economic benefit. Promising alternatives are double side coated Anti Reflex glass (Hemming et al., 2006a), micro-V treated glass (Sonneveld & Swinkels, 2005a) or triple layer systems (Bot et al., 2005).

**Energy efficient operational control**

Energy efficient environmental control depends on available hardware and physiological knowledge. For example, it has been known for decades that crops react primarily to the average daily temperature rather than to the exact 24 hours temperature course (e.g. de Koning, 1988). Compensating cooler with warmer periods has a significant potential for energy saving. Simulations and experiments with this so-called temperature integration show that 5 to 15% can be realised without affecting plant growth or production (e.g. Körner & Challa, 2003; Dueck et al., 2004; Elings et al., 2005). Today, almost all commercial greenhouse control systems are equipped with the temperature integration feature. Again, the practical use of this option has so far been limited due to the low economic benefits (Elings et al., 2005).

During periods with relatively low radiation and moderate ambient temperatures, natural or forced ventilation is generally used to prevent (too) high humidity. The resulting energy loss is significant: 5 to even 20% (Campen et al., 2003). Increasing the humidity set point by 5% was predicted to save 5 to 6% energy (Elings et al., 2005). The first practical experience in closed greenhouses show that growers gradually shift their set points to higher temperature and humidity levels during the (summer) daytime, which may partly explain the positive yield and energy efficiency effect observed (Raaphorst, 2005).

In order to maximally profit from environmental control, the control should no longer be aimed at environmental factors or actuators like heating, ventilation and CO2 supply, but on (energy efficient) crop production and quality. This requires (model based) control systems which take into account the impact of various actions on crop production (and energy consumption). This approach has been taken ever since Challa and van de Vooren (1980) first described an optimisation routine weighing energy consumption against earliness of cucumber production in the early 1980ies. Next steps were using relatively simple models on crop photosynthesis and transpiration, followed by more sophisticated physical models (e.g. Stanghellini, 1987; van Henten, 1994) and photosynthesis models (Körner & van Ooteghem, 2003). Parts of these models are used in commercial environmental control systems but the primary use is in design studies, for example on the optimisation routine for temperature and CO2 as developed by Dieleman et al. (2005). The results are now also available as a CO2 optimiser which can be downloaded from several web sites (e.g. www.energiek2020.nu). Another step towards energy efficient operational control is the model based humidity control (Körner & Challa, 2003) which improved the humidity routine to avoid fungal diseases like grey mould (e.g. Körner & Holst, 2005). Although high humidity levels are generally associated with increased risk of fungal diseases (e.g. Botrytis, blossom end rot), increasing humidity may also have positive effects on crop production and quality (e.g. Montero, 2006). Therefore, increasing the humidity level should be considered an effective way of increasing energy efficiency.

**Integral design**

The only way to reach the ambitious targets of -30% CO2 emission is by integrating energy conservative greenhouse systems including covering material, heating and ventilation/dehumidification, control algorithms and energy conversion systems. A general and widely applicable design method for energy conservative greenhouses, based on methodological
design procedures, has been suggested by van Henten et al. (2006). This design tool is coined ‘the adaptive greenhouse’. It aims at conceptual designs for protected cultivation systems, adapted to local climatic conditions.

**Completely controlled environment greenhouses**

Completely closed greenhouses (e.g. Opdam et al., 2005) are designed to combine improved production with energy saving. Reduced air exchange allows maintaining higher CO₂ levels and thus achieving higher yields. Energy can be saved by extracting the heat surplus during the summer and reusing it during the winter. The first results with completely closed greenhouses with forced cooling have shown that tomato production increases up to 20% and energy savings up to 30% can be reached (de Gelder et al., 2005). A further challenge is the so called ‘energy producing greenhouse’, designed for pot plants. In this system, the performance of the greenhouse as a solar collector is maximised by very efficient heat exchangers (Bakker et al., 2006). Theoretically, a year round heat production of about 800 MJm⁻² can be reached, equivalent to 25 m³ natural gas (de Zwart & Campen, 2005). In the first trials in a commercial scale greenhouse, this heat production appeared hard to achieve. The limiting factor was the temperature band width plants can tolerate (de Zwart & van Noort, 2007). The crop production, however, increased significantly. The potential of these systems is high, since they enable controlling the various environmental factors (temperature, humidity and CO₂) independent of the radiation level.

Up till now, none of the completely closed greenhouses have shown to be economic competitive. Limiting factors include: still too low energy prices, limited yield increases and high investment costs for the very complex installations. Alternatives called ‘semi-closed greenhouses’ are now being developed for crops like sweet pepper, cucumber, strawberry, pot plants, rose and phalaenopsis. In these systems the cooling capacity is lower, so at maximum solar radiation additional ventilation is needed. Most of these systems use direct evaporative cooling by misting, as this still gives the best economic results (Bakker et al., 2007). To support the growers in their decisions, a design tool has been developed to compare the different systems (de Zwart, 2007). Since the potentials for both production control and energy saving are big, the greenhouse sector and the government have set up a new research and development programme to gain the necessary information for optimisation and further implementation of the systems in commercial practice. In the first years, this research programme will focus on the effects of the new combinations of temperature, light, humidity and CO₂ on production (Dieleman, 2007), quality and pests and diseases.

In the future, specific materials absorbing or reflecting different wave lengths or containing photo- or thermochromic pigments may be used to bring down the heat load (Hoffmann & Waaijenberg, 2002). Materials reflecting parts of the sun’s energy not necessary for plant growth (near-infrared radiation, NIR) appear promising (e.g. Hemming et al., 2006c) and may be applied either as greenhouse cover or as screen material. The conversion of this NIR energy into electric power might be a next step in the design of completely controlled and even energy producing greenhouses. Sonneveld et al. (2006, 2007) described a system with a parabolic NIR reflecting greenhouse cover. This cover reflects and focuses the NIR radiation on a specific PV cell or solar collector to generate either electricity or steam. So far, the electric power generated is not sufficient for a heat pump with enough capacity to keep the greenhouse completely closed. Still, the NIR reflecting cover reduces the heat load significantly and has a positive effect on the economic feasibility of (semi-)closed greenhouses.
Conclusions

Recent developments in production systems strongly effect the greenhouse environment and the cultivation systems. So far, the major developments towards sustainable production systems are driven by production increase and (energy and labour) cost reduction. Plants move through the greenhouse in mobile cropping systems. Environmental factors change and new combinations of temperature, humidity, light, light spectrum, CO₂ and air movement arise in energy saving and completely controlled greenhouses. Expected consequences for the occurrence and control of pests and diseases are discussed by van der Lans et al. (2008).

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Study of the efficacy of different concentrations of insecticidal soap, in comparison oxydemeton-methyl (Metasystox) to control *Aphis gossypii* in greenhouse cucumber

Valiollah Baniameri
Iranian Research Institute of Plant Protection (IRIPP), P. O. Box: 19395/1454 Tehran, Iran, E-mail: baniameri@yahoo.com

**Abstract:** Insecticidal soaps have been used to control insects and mites because of low toxicity and environmental pollution with no residual effect. At present time, because of limitation in the use of chemical insecticides in greenhouse vegetables, it is needed to use an alternative product without poisoning active ingredient such as soaps. In this study, the effect of an insecticide soap named Palizin (Kimiasabzavar product) with three different concentrations (1.5, 2.5 and 5 g/l), oxydemeton-methyl (Metasystox) (1 ml/l) and control were evaluated through a CRBD in 3 replications against *Aphis gossypii* in greenhouse cucumber of Tehran and Varamin, Iran. Mortality percentage was calculated using Henderson-Tilton formulae and the arcsine transformed mortality percentage of aphids were analysed by SAS software. The comparison of the mean effectiveness of all treatments showed that there was no significant difference among treatments, but there is a significant difference to the control. The maximum and minimum mean effect of insecticide soap were 90.63 and 75.89 percent in concentrations of 2.5 and 1.5 g/l, respectively. According to the results, insecticidal soap (Palizin) is recommended in 2.5 g/l for spraying application.

**Key words:** insecticidal soap, *Aphis gossypii*, greenhouse cucumber, Metasystox, Iran

**Introduction**

Cucumber is the main greenhouse vegetable in Iran, with 95% of the greenhouse grown area (3,500 ha). Cucumber is attacked by various pests including aphids, of which the cotton aphid *Aphis gossypii* Glover is one of the main species in open field and greenhouses. At present time, because of limitation in the use of toxic synthetic chemical insecticides in greenhouse vegetables, it is needed to use alternative products without poisoning active ingredient such as soaps. Insecticidal soaps have been used to control insects and mites because of low toxicity and environmental pollution with no residual effect. Up to this date, practically no official research projects have been performed in Iran on the insecticidal properties of soaps, while in some other countries application of insecticidal soaps to control sucking insects on greenhouse vegetable crops, has become an increasingly common practice.

Experiments have proven that insecticidal soaps can cause high fatality rates in a variety of soft bodied insect pests such as aphids, whiteflies, leaf hoppers, thrips, scale insects. Butler *et al.* (1993) studied the effect of different formulations of horticultural oils and insecticidal soaps on whitefly populations on pumpkins and tomatoes and concluded that a 1% concentration of insecticidal soap caused 85% mortality of whitefly immature stages. Gill and Raupp (1989) achieved 100% and 85% mortality rates, respectively, in their comparative study of insecticidal effects of Acephate (0.125%) and insecticidal soap (2%) on Azalia scale insects Zinnin and Vachris (1990) studied the effect of insecticidal soaps on aphids as vectors of TMV virus to find that concentrations of between 0.1 to 10 percent controlled the disease causing pests population 35 to 92%, respectively, compared to control treatment (water).
Heinz et al. (1998) during an IPM program effectively controlled sucking insects such as aphids in greenhouses by spot application of insecticidal soap and releasing green lacewings as aphid predators. Imai et al. (1997) studied the effect of relative air humidity on efficacy of insecticidal soaps and concluded that the efficacy of insecticidal soaps is adversely affected by decrease in relative humidity.

In this study the efficacy of different concentrations of a new brand of insecticidal soap manufactured by Kimiasabzavar company in Iran under the trademark Palizin in controlling A. gossypii has been compared with a systemic organophosphorous insecticide oxydemeton-methyl (Metasystox).

Palizin insecticidal soap contains coconut diethanolamine as the main active ingredient. This is a mildly alkaline compound (pH= 7.5-8 at 2.5 g/l) with very low oral toxicity (LD₅₀ > 12,200 mg/kg). Soaps dissolve the waxy layer on insects body and damage the cell membrane. Saponification of the lipids in the cell tissues results in the cell membrane rupture and loss of vital fluids.

Materials and methods

To study the effect of a new brand of insecticidal soap under the trademark Palizin to control of A. gossypii and to determine the optimum dosage of this product, a one year research project was designed.

In this study a comparison was made among Palizin at three different concentrations, the systemic organophosphorous insecticide Metasystox and a control treatment (water).

Tests were performed as complete random blocks with 5 replications, at two locations, the pilot greenhouse in Tehran and a commercial greenhouse in the city of Varamin.

Insecticide treatments

The treatments were: Palizin (water soluble formulation) at 1.5, 2.5 and 5 g/l, Metasystox (EC formulation) at 1 ml/l and water as control treatment.

The tests were carried out in a 500 m² greenhouse where cucumber seeds (Negin variety) were planted. The test site was divided into 5 plots. Three replications were made, each in a 14 meter long row. Spraying the soap solution was performed for three times in 2 to 3 days intervals using a high pressure engine driven spray equipment with a triple nozzle. Metasystox emulsion at 1 ml/l was sprayed only once, using the same equipment.

Data collection and analysis

Samples were taken once before and four times in 1, 3, 5 and 10 days intervals after the application of pesticides. To collect samples properly, 10 leaves of equal sizes (third leaf from top of the plant) were randomly chosen and picked. The samples were then transferred to the laboratory in labelled plastic bags, and live aphids were carefully counted in a 2-cm² frame which was placed randomly on the backside of each leaf.

The same procedure was followed in another test site, a cucumber greenhouse located in Varamin with the exception that samples were taken in 1, 3 and 5 days intervals.

The tenth day sampling was cancelled due to heavy infestation of a neighbouring alfalfa farm with aphids, which was being harvested the same day and could interfere with sampling and lead to false results.

The collected data were converted into percent mortality using Henderson Tilton formulae. To minimize variance of the data, they were converted by Arcsine method and analysed in complete random block design using SAS software. All treatments were statistically compared by Duncan multiscan test.
Results and discussion

The final results obtained on the effect of different concentrations of Palizin insecticidal soap in controlling *A. gossypii* at two test sites are shown in tables 1 and 2. Statistical analysis showed no significant differences among soap treatments and Metasystox insecticide. Analysis of the data collected in Varamin showed the same results. But in Tehran a significant difference was observed between soap treatment at 2.5 g/l and other treatments. According to the results of Tehran test, the mean highest percent mortality (90.63%) occurred at 2.5 g/l soap concentration and the mean lowest (75.89%) at 1.5 g/l.

The comparison of the mean effectiveness of all treatments showed that there were no significant differences among treatments, but there is a significant difference with control. A 100% mortality, observed in a sample unit (2-cm² frame) is an estimation of the overall mortality and does not necessarily mean that the entire population of aphids in the test plot was destroyed by the treatment.

Table 1. Mean percentage mortality of *Aphis gossypii* with different treatments in Varamin.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Average percent mortality in following observation days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Palizin 1.5 g/l</td>
<td>93.55</td>
</tr>
<tr>
<td>Palizin 2.5 g/l</td>
<td>77.49</td>
</tr>
<tr>
<td>Palizin 5 g/l</td>
<td>100</td>
</tr>
<tr>
<td>Metasystox 1 ml/l</td>
<td>99.7</td>
</tr>
</tbody>
</table>

Table 2. Mean percentage mortality of *Aphis gossypii* with different treatments in Tehran.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Average percent mortality in following observation days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Palizin 1.5 g/l</td>
<td>86.78</td>
</tr>
<tr>
<td>Palizin 2.5 g/l</td>
<td>93.90</td>
</tr>
<tr>
<td>Palizin 5 g/l</td>
<td>97.81</td>
</tr>
<tr>
<td>Metasystox 1 ml/l</td>
<td>88.74</td>
</tr>
</tbody>
</table>

The primary reason for unexpected decrease in mortality at 1.5 g/l soap treatment at 5 days in Tehran test site appeared to be the placement of live aphids on the plants by ants. To avoid false results, ants were eliminated at their nest.

Similar results were obtained by Zinnin and Vachris (1990) with insecticidal soaps on aphids as vectors of TMV virus who found that a concentration of 10 percent controlled the disease causing pest populations by 92%.

Soaps are more likely to cause damage to plants when applied in hot weather and under the sun. Some plants are more sensitive to soap solutions and can be seriously damaged, so spot tests prior to complete application are strongly recommended.

Considering the satisfactory results obtained the use of Palizin insecticidal soap as a safe alternative to synthetic pesticides in controlling aphids in greenhouses is recommended.
**Tips for obtaining optimum results with the insecticidal soap Palizin**

1. Palizin is a contact insecticide. So the soap solution has to come into direct contact with the insect body and cover the whole body with a thin layer of solution to be most effective. Installing triple nozzles on spraying equipment is strongly recommended, since it ensures thorough coverage of infested plant parts, which is essential to proper pest control with soap solutions.

2. To achieve the highest control of insect pests and avoid phytotoxicity, spraying of soap solution must be done early in the morning or at evenings when the weather is cooler and the relative humidity is at its highest.

3. Do not spray on young transplants and flowering plants with delicate petals, before performing a spot test and waiting for at least 48 hours to check for any probable damages.

4. Avoid spraying soap solution, during drought and on plants under severe nutritional or watering stress.

**Acknowledgments**

I thank Dr. A. Sheikhi from IRIPP for statistical advice and Eng. S. Ahmadi for technical helps.

**References**


The switch to IPM in cut-chrysanthemum in the Netherlands

Ellen Beerling
Wageningen UR Glasshouse Horticulture, Violierenweg 1, 2665 MV Bleiswijk, The Netherlands, E-mail: ellen.beerling@wur.nl

Abstract: Within a few years time Dutch cut-chrysanthemum growers switched to IPM. In this paper we describe the causes that account for this change, and we summarize our research on thrips and spider mite control that contributed to it.

Key words: chrysanthemum, IPM strategies, biological control, western flower thrips, spider mites, pesticides, Amblyseius cucumeris, Amblyseius swirskii, Hypoaspis spp., Steinernema feltiae, Verticillium lecanii, Phytoseiulus persimilis

Introduction

Around the turn of the millennium Dutch cut-chrysanthemum growers regarded integrated pest management (IPM) as not feasible. Several reasons were posed for this attitude: 1) since the whole plant is marketed, the threshold for cosmetic damage is low; 2) a growing cycle is too short for natural enemies to develop a population (from planting to harvest: around 11 weeks); 3) high expenses of inundative release of natural enemies in every cycle (i.e. five times a year); 4) a zero tolerance for pests and beneficials on export products (van Lenteren, 2000; Lindquist & Short, 2004).

Only a few years later, in 2005, the majority of the chrysanthemum growers appear to consider IPM a feasible option. In 2007 most of them apply an IPM-strategy with at least one biological control agent. What has happened in the meantime to cause this change?

Analysis of the problem

IPM strategies
Since decades, members of our working group, especially from the UK, have attempted to introduce IPM programs in chrysanthemum (Scopes & Biggerstaff, 1973). In the Netherlands, these programs never became widespread. The main cause was the control of western flower thrips, Frankliniella occidentalis. Available natural enemies like Amblyseius cucumeris, Verticillium lecanii and Orius spp. were not effective enough. In the soil-based cut-chrysanthemum cultivation, few insecticides are registered. Those that are effective against thrips lack the necessary selectivity for IPM programmes.

Chemical control strategies
The chemical control strategies were also facing difficulties. Growers were increasingly having problems controlling spider mites and leafminers (Liriomyza spp.), apparently caused by overuse of abamectine (Vertimec). The trend of planting at higher density made it more difficult to get sufficient spray coverage. Registration of new acaricides could not completely compensate for the ban of dienochlor (Pentac), an acaricide that was cheap, effective, persistent and vapour-active.
Contributions to the switch to IPM

There are various motives why growers will or will not switch to IPM (de Buck & Beerling, 2005). We believe that essentially four factors account for the switch of the chrysanthemum sector towards IPM: 1) increasing problems with chemical control of spider mites (and leafminers), 2) high costs of new acaricides, 3) the societal and governmental pressure towards sustainable production, and 4) new data on efficacy and integration of natural enemies and pesticides in chrysanthemum. The latter was the result of a combined effort of basic research in experimental glasshouses, and implementation research at commercial glasshouses carried out by biocontrol producers and advisors, and supported by knowledge transfer projects (Strateeg and Farming with Future; De Buck & Beerling, 2005).

An overview of the implementation, research and current IPM strategies are given in Zuijderwijk et al. (these proceedings). In the next paragraphs the results from our basic research are summarised.

Building blocks for IPM

A problem analysis learned that the natural enemies for controlling thrips should be evaluated specifically for chrysanthemum. As an alternative to synthetic pesticides, natural pesticides and new synthetic acaricides should be examined for efficacy and selectivity, meant to develop a feasible IPM programme.

Amblyseius cucumeris

The predatory mite *A. cucumeris* has been successfully applied for controlling thrips in a wide variety of crops. It was uncertain if this predator could be successful in chrysanthemum. The assumption was that during the first few weeks of chrysanthemum growing the climate in the (still open) crop is too harsh and that the predators would not be able to establish a population due to chemical residues on the cuttings and a too short growing period.

To test whether it would be feasible to apply *A. cucumeris* from shaker bottles (rather than breeding sachets), the predators were introduced directly on cuttings just before transplanting at a density of 100 mites per m² (1.3 mites per cutting). After three and seven weeks we were able to recover some predatory mites (0.2-0.3 per cutting), suggesting that the mites were hardly able to establish in this crop. Whether in practice any predatory mites will survive these first weeks depends on the availability of food and the presence of residues.

Introducing *A. cucumeris* in breeding sachets was thought to overcome this problem because of the constant production of predators from a protected breeding place. Apart from predatory mites, the sachets contained *Tyrophagus* sp. as food mites. In the period of 2002-2004, *A. cucumeris* breeding sachets (1,000 predatory mites/sachet) were evaluated in a series of glasshouse experiments on different IPM strategies. For most trials an experimental glasshouse compartment of 300 m² was used, divided in experimental plots of 2-6 m² (Beerling & van den Berg, 2005). All plots were equally infested with western flower thrips. The following conclusions were drawn.

- With 1 sachet/m², a reduction of the thrips population up to 75% could be reached
- The numbers of predatory mites recovered from the crop at harvest, nine weeks after introducing the predator sachets, varied from just a few up to 15 per plant, depending on cultivar and availability of food. This is relatively low compared to the numbers released: 1,000 predatory mites in the sachets per m² equals approximately 14 predators per plant, suggesting that there was hardly any population build-up. We concluded that in a
chrysanthemum crop suppression of thrips solely depends on an immediate effect of the released predatory mite

*Amblyseius swirskii*

More recently, we started to evaluate whether *A. swirskii* would be a more effective thrips predator. Generally, in chrysanthemum there does not seem to be a significant difference in efficacy between the predatory mites.

- Both predators were less effective as a thrips predator when spider mites were present as an alternative prey. This affected *A. swirskii* more than *A. cucumeris*
- The cultivar seems to play a role in the efficacy as spider mite and thrips predator. On the spider mite susceptible (and partly thrips resistant) cultivar Woodpecker *A. swirskii* was a more effective predator, while on a thrips susceptible (and partly spider mite resistant) cultivar Euro *A. cucumeris* was more effective. We have planned laboratory studies to clarify this phenomenon

*Hypoaspis spp.*

A few growers have been using *H. aculeifer* and *H. miles* to control thrips pupae in the soil. In a series of three glasshouse trials the standard dose of 100 per m² was compared to higher doses (up to 1,000 m²) of both predatory mites. Neither species nor doses resulted in a noticeable control of thrips. Soil samples did not reveal any difference from untreated controls, either in predatory mite numbers or in species composition. Therefore, it is not advised to apply *Hypoaspis*-species against thrips in chrysanthemum.

*Steinernema feltiae and Verticillium lecanii*

In 2002, a glasshouse experiment on cut-chrysanthemum was carried out with *S. feltiae* (Nemasys F) and *V. lecanii* (Mycotal/Addit). Nine weekly sprays were compared to a water control and a chemical reference (spinosad, applied twice). To assess the effect on *A. cucumeris*, this predatory mite was introduced (1 sachet per m²) in half of the plots (Beerling & van den Berg, 2005).

- Nine weekly sprays of *S. feltiae* resulted in a considerable reduction (74%) of thrips on plants
- When *S. feltiae* sprays were combined with *A. cucumeris* (1 sachet/m²), thrips control was improved to 96% compared to the untreated control
- Nine weekly sprays of *V. lecanii* reduced thrips populations by 38% after six weeks and by 14% at harvest. In two earlier experiments, five applications of *V. lecanii* (Mycotal without Addit) reduced the number of thrips by 60% and 85% respectively. The variability observed should be subject to further study
- The control of thrips by the predatory mites (75%) was increased to 90% when combined with weekly *V. lecanii* sprays

In spite of the considerable effects observed, there was still unacceptable damage to the crop, especially in thrips susceptible cultivars. Another complicating factor for using mycopesticides like Mycotal is the widespread use of fungicides against white rust (*Puccinia horiana*).

*Integrated spider mite control*

In a 300 m² experimental glasshouse trials were carried out to compare spider mite control strategies.
Phytoseiulus persimilis proved to be a very effective spider mite predator when released at sufficient numbers (in our trials: 12 predatory mites per m²).

In general, IPM-strategies resulted in a three- to tenfold better spider mite control than chemical strategies.

An IPM-strategy with two initial applications of bifenazate or spiromodol and subsequent introduction of P. persimilis (12/m²) eradicated the spider mite population, whereas a current chemical strategy (two sprays of bifenazate (Floramite), two sprays of abamectine (Vertimec) and one final spray of tebufenpyrad (Masai)) resulted in an only 75% control.

An alternative IPM-strategy with abamectine (Vertimec) or milbemectine (Milbeknock) and P. persimilis was only slightly better than the chemical strategy.

In an IPM-strategy with P. persimilis for spider mite control and Mycotal for thrips control, it was shown that the Mycotal adjuvant Addit negatively affected the biological spider mite control (30% less control compared to Mycotal without Addit).

Conclusions

P. persimilis appears to be a solid base for integrated spider mite control in chrysanthemum. Thanks to the efficacy of this predator corrective sprays with acaricides can be kept at a minimum, which reduces the risk of resistance development. Thrips control, however, is still cumbersome. The success of biological thrips control depends largely on the level of infestation and the susceptibility and damage threshold of the cultivar. On thrips susceptible cultivars, the best option is to apply a combination of predatory mites (A. cucumeris or A. swirskii) and repeated applications of pathogenic nematodes (S. feltiae) or mycopesticides (Mycotal, Botanigard). Growers should weigh the high costs of this program against the benefits of biological spider mite control. Further reduction of the pesticide arsenal due to legislation and resistance may change the picture. Long-term solutions include more effective natural enemies for western flower thrips and less susceptible cultivars of chrysanthemum.

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References


Development of a grower rearing-release system for *Atheta coriaria*, for low cost biological control of ground-dwelling pest life stages

Jude Bennison¹, Kerry Maulden¹, Heather Maher¹, Monique Tomiczek²
¹ADAS Boxworth, Boxworth, Cambridge, CB23 4NN, UK, E-mail: jude.bennison@adas.co.uk; ²Formerly of ADAS Boxworth

Abstract: Following Canadian research and experience on the potential of *Atheta coriaria*, for biological control of sciarid flies, shore flies and western flower thrips (WFT), further research was done in the UK to develop a practical grower rearing-release system for the predator for low cost biological control of various pests. The system gave promising reductions in numbers of WFT on *Impatiens* and of sciarid flies on potted parsley. *A. coriaria* release rates needed for control of sciarid flies of a specific density on potted parsley were determined. A method for manipulating *A. coriaria* release rates from the rearing-release containers was identified. Further development and testing of the rearing-release system is needed before grower uptake can be recommended.

Key words: *Atheta coriaria*, sciarid fly, shore fly, western flower thrips, biological control

Introduction

Canadian researchers developed a rearing method for the staphylinid beetle, *Atheta coriaria*, using trout food as an artificial diet, and their laboratory studies showed that *A. coriaria* was a voracious predator of the ground-dwelling life stages of sciarid fly, *Bradysia impatiens*, shore fly, *Scatella stagnalis* and western flower thrips (WFT), *Frankliniella occidentalis* (Carney et al., 2002). Canadian research also showed that *A. coriaria* reduced numbers of WFT in roses in research glasshouses (G. Murphy, pers. comm.). Adding trout food to pots of growing media was used for monitoring *A. coriaria* in commercial glasshouses (Carney et al., 2002) and also as a potential method for aiding their establishment (G. Murphy, pers. comm.). *A. coriaria* is now available for control of sciarid and shore flies, and most suppliers state that some incidental control of thrips may also be given. In the UK, direct releases of *A. coriaria* did not control shore flies, *Scatella tenuicosta* on potted mint (Bennison et al., 2005) and grower direct releases at recommended rates in various crops have given unreliable results against both sciarid and shore flies. In 2004, a UK nursery (WJ Findon & Son) experimented with using ‘breeding boxes’ for establishing *A. coriaria* in crops of poinsettia and cyclamen. The boxes produced and released large numbers of predators at very little cost, and sciarid flies did not cause problems in either crop. However, other growers trying the system had variable success. Problems occurred with variable production rates of *A. coriaria* and contamination of the boxes with fungi and undesirable insects and mites. This paper summarises some aspects of our research, aiming to further develop and test an improved rearing-release system for *A. coriaria* for control of various ground-dwelling pests.

Materials and methods

Design of rearing-release system

*A. coriaria* were reared in plastic boxes, using a very similar method to that developed by
Carney et al. (2002), but using turkey starter crumbs (Dodson & Horrell Ltd., UK) as a food source, rather than ground trout pellets. A previous experiment had shown that turkey crumbs led to similar A. coriaria development rate and population growth as trout pellets (Bennison, 2007). Turkey crumbs are preferable to trout pellets as they are supplied ready ground for incorporation into the rearing medium, they are cheaper, and unlike trout pellets, they do not have a strong odour or high oil content, both of which had caused problems with using rearing-release boxes on nurseries. Each 3-litre plastic box contained 1.5 litres of dampened coir and vermiculite substrate and had a snap-on lid, fitted with two ventilation holes covered with insect-proof mesh. Sixty A. coriaria adults were added to each box and every 3–4 days, 2.5 g of turkey crumbs, and water as required, were added and incorporated into the substrate. The boxes were kept at 25°C, 16:8 L:D for 23 days. Previous experiments had shown that under these conditions, the next generation of adult A. coriaria developed after 19–23 days, and that the mean population growth was × 20, e.g. 60 adults led to a mean of around 1,200 mixed adults and larvae after 23 days (Bennison, 2006, 2007). These results are similar to those of Carney et al. (2002), who used trout pellets as food. The rearing boxes (once at least 23 days old) were adapted for use as rearing-release boxes in subsequent glasshouse experiments, by removing the mesh from the ventilation holes, thus allowing A. coriaria to escape, and by adding holes in the base, to allow water uptake in various irrigation systems. During the glasshouse experiments, each box was fed with 5 g of turkey crumbs every week.

**Experiment with WFT on Impatiens**

During May and June 2006, three insect-screened research glasshouses (each 16 m²) were used to evaluate WFT control on Impatiens by A. coriaria, using the rearing-release box system. Although WFT on Impatiens can usually be controlled adequately by Amblyseius cucumeris, Impatiens is a good experimental host plant for the pest and served as a model plant to test the A. coriaria system. Each glasshouse contained 48 pots of Impatiens, stood on the floor on capillary matting. Six WFT larvae were added to each of 10 plants in each glasshouse. One A. coriaria rearing-release box was placed in the middle of each of two replicate glasshouses and the other glasshouse was used as the untreated control. The boxes had been prepared using the method described above, and each contained an estimated 1,200 A. coriaria adults and larvae. Two ‘bait pots’ (pots of damp compost mixed with turkey crumbs) per glasshouse were used to monitor A. coriaria dispersal; the pots were replaced each week after counting adults and larvae. Six weeks after the experiment was set up, numbers of WFT adults, larvae and pupae per plant were recorded on the same ten infested plants in each glasshouse, using a destructive sampling and alcohol washing method. Total numbers of WFT per plant in each glasshouse were compared using paired t-test.

**Experiments with sciarid fly on parsley**

A previous experiment (not reported in detail here) in June 2006 tested the rearing-release system for control of sciarid flies, Bradysia difformis, and shore flies, Scatella tenuicosta on a commercial pot herb nursery. The system was easy to maintain by nursery staff. Shore flies on mint were largely controlled by an exceptionally high population of the naturally-occurring shore fly parasitoid, Aphaereta debilitate. A. coriaria gave a significant (59%) reduction of a high density of sciarid flies on parsley over the 4-week production period (Bennison, 2007). As no data was available on how many A. coriaria are needed to give good control of a specific density of sciarid flies on parsley, an experiment was done in June 2007 to address this need. Sixty pots of parsley were collected from the same herb nursery, one day after the newly germinated plants were placed in the production glasshouse. Pots were selected with similar numbers of sciarid fly eggs visible on the compost surface. Each pot was placed inside
a larger individual ‘emergence pot’. *A. coriaria* adults were added to each pot (0, 1, 2, 5 or 10 per pot), with 12 replicate pots per treatment. Each emergence pot was covered with insect-proof mesh, secured with a rubber band. The pots were placed in a glasshouse, with minimum temperature 19°C, as used on the herb nursery. The compost was watered as necessary through the mesh lids. After two weeks, a small yellow sticky trap was secured to the inside of each emergence pot. After a further eight days, numbers of sciarid fly adults per trap were recorded, and any adults and larvae remaining in the pots or compost were assessed by visual inspection and Tullgren funnel extraction respectively. Total numbers of sciarid flies per pot in each treatment were compared using analysis of variance.

**Results and discussion**

**Experiment with WFT on Impatiens**

Both *A. coriaria* adults and larvae (up to 16 per pot per week) were found in bait pots throughout the experiment, demonstrating that the beetles dispersed from the rearing-release boxes and entered and bred in the pots. *A. coriaria* adults were also frequently observed under both bait pots and *Impatiens* pots. At the end of the experiment, mean numbers of WFT (all life stages) on the *Impatiens* were significantly lower in the two glasshouses with *A. coriaria* rearing-release boxes (38 and 97 per plant respectively) than in the untreated glasshouse (209 per plant). These results represent 82% and 53% reductions in WFT numbers in the two treated glasshouses respectively. Very few pupal stages (one prepupa and four pupae) were found on the 30 assessment plants from the three glasshouses, indicating that most WFT larvae dropped to the compost or ground to pupate, and were thus available for predation by *A. coriaria*. This result is consistent with those reported in American research, where most WFT immature stages found on *Impatiens* were larvae (Ugine *et al.*, 2006; Ugine, pers. comm.). The control given by *A. coriaria* of the very high density of WFT used in this experiment, although significant, was not sufficient. However, using rearing-release boxes prepared with higher numbers of *A. coriaria* could have led to better WFT control, and the system used in this experiment might give adequate control of lower WFT densities, or be used as a low-cost supplement to other biological control agents e.g. *Amblyseius cucumeris*. Further development and testing of the rearing-release system is needed before it can be recommended for grower uptake on a large scale.

**Experiments with sciarid fly on parsley**

Adding *A. coriaria* adults at five or 10 per pot (equivalent to 500 or 1,000 *Atheta* per m² on the commercial herb nursery before pot spacing) reduced mean numbers of sciarid flies 22 days later, from 11.4 per pot in untreated pots, to 3 and 1.7 per pot respectively (75% and 85% reductions respectively) (Figure 1). Adding *A. coriaria* at one or two per pot (equivalent to 100 and 200 per m² on the nursery before pot spacing) did not significantly reduce numbers of sciarid flies. The effective rates of *A. coriaria* were much higher than the maximum direct release rates recommended by suppliers (up to 10 per m²) and would be economically unacceptable for growers if bought from suppliers. However, such release rates might be possible using the grower rearing-release system. A recent glasshouse experiment using insect-proof cages (not reported in detail here) demonstrated that numbers of *A. coriaria* leaving rearing-release boxes could be manipulated by adjusting the feeding regime. Boxes that had not been fed for a week released significantly more (×7) beetles during the following week than those that were fed as usual with turkey crumbs. Thus the system could be manipulated to give a quick, low-cost inundative release of hungry beetles when needed, e.g. when placing new plants into a glasshouse with high target pest densities. Further research is planned on how to manage the rearing-release system for sustained release of sufficient *A. coriaria* for cost-effective control of various ground-dwelling pests on a range of crops.
Figure 1. Mean numbers of sciarid flies per pot of parsley, 22 days after adding *Atheta* adults at different rates per pot. ** significantly lower than in untreated controls (*P*<0.01).

**Further research**

Only some of our work with *A. coriaria* could be summarised in this paper. Further information is available from the main author. Further development and testing of the rearing-release system on commercial crops is needed before it can be recommended for grower uptake.

**Acknowledgements**

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Strategies for aphid control in organically grown sweet pepper in the Netherlands

Chantal Bloemhard, Pierre Ramakers
Wageningen UR Greenhouse Horticulture, P.O Box 20, 2665 ZG Bleiswijk, The Netherlands, E-mail: chantal.bloemhard@wurl.nl

Abstract: Within the framework of a ministerial program to encourage organic farming, a knowledge dissemination project on biological pest control was started. Organic sweet pepper growers participating in this project have adopted a more preventive strategy, especially with respect to aphid control. Natural enemies were released at much higher rates and frequencies, and repairing sprays with natural pyrethrum could be omitted. Crops still suffer from honeydew pollution and yield losses. Results of scouting both aphids and natural enemies in a representative case are presented.

Key words: aphids, biological control, greenhouse, sweet pepper, organic farming

Introduction

Approximately 1% of the greenhouse vegetables in The Netherlands are produced according to the demands of organic farming, that is planting in soil, abandoning synthetic fertilisers and pesticides, and limiting the input of animal manure. In organically grown sweet peppers, aphids are the most important pest. Since the modern systemic aphicides used in integrated control are not available to these growers, they rely on biological control exclusively. Obviously, the wide range of natural enemies of aphids commercially available is not a guarantee for successful control, rather an indication that this problem is difficult to tackle. Myzus persicae is the most important species. Pollution of the crop by honeydew caused by this species forces the growers to invest a considerable amount of labour in cleaning the fruits after harvesting. Aulacorthum solani causes growth disorders; eventually, affected plants completely stop producing.

This project was part of a program of the Ministry of Agriculture, Nature and Food Quality for stimulating organic production in greenhouses. At the beginning of this century, technology transfer projects were popular. They were based on the assumption that relevant information tends to pile up on the shelves of scientists, without ever reaching horticultural practice. The idea was to improve cropping systems by intensifying exchange of knowledge and experiences between growers, advisors and researchers. This paper describes a five years technology transfer project that focused on improving pest control in organic production of sweet peppers in greenhouses. The impact of this project on aphid control is evaluated in retrospect.

Methodology

Organic growers choose to grow more than one crop simultaneously or alternately. The main crops of our growers were tomato and sweet pepper. Additionally, cucumber and eggplant were cultivated.

A core group of five growers was visited every fortnight. On that occasion, an inspection
of the crop was done together with the grower, his scout or IPM advisor. The general control strategy was discussed, the pest control measures (mainly releases of natural enemies) were recorded and ways to proceed were suggested. Another five growers were visited just twice a year. Their crop protection operations were registered either by the growers themselves or by their IPM advisors, and the content of these logbooks were added to the project dossier.

Intensive scouting was carried out in one greenhouse compartment of 2,500 m² in the year 2005. Randomly chosen leaves were inspected with a magnifying glass. Sample size was 1,200 leaves on young plants and 1,680 on the fullgrown crop. The parameter for aphids was presence/absence per leaf (leaf incidence). The abundance of each natural enemy was roughly scored in four classes, defined in proportion to the aphid colony they were found in:

- class 0 = not found
- class 1 = present
- class 2 = more abundant, but still outnumbered by the aphids
- class 3 = enough to clear the aphid colony

Once a year, the researchers organised a meeting for the growers, their advisors, and technical specialists representing crop protection suppliers and biocontrol companies. Strategies were evaluated, and the possibilities and restrictions of biological control were discussed. The progress of the project was reported in more general terms via an annual publication in a magazine, and continuously on a web site.

Results

Tabel 1 lists the data from those growers that participated throughout the duration of the project. Of course, organic growers were already using various natural enemies against aphids (see section ‘2002’ of Tabel 1). Most growers introduced *Aphidoletes aphidimyza* and at least one of the braconid parasitoids; some used a wide spectrum of natural enemies. The success of aphid control, however, was not clearly correlated with the number of species being released. All crops suffered from honeydew pollution, and growers frequently had to intervene with an insecticidal soap as a first step, usually followed by natural pyrethrum in more serious cases.

In the course of the five years that this project was running, the growers adopted a more systematic approach towards introduction of natural enemies. This included starting earlier, using recommended rates and frequencies, and continuing releases after the pest was thought to be under control. All this added up to a much higher “consumption” of natural enemies, especially of *A. aphidimyza* (Tabel 1). Repairing sprays were no longer carried out, not by the project growers that is. Still all crops suffered from honeydew pollution, and fruits still had to be cleaned.

The spectrum of natural enemies species used did not change drastically. Changes observed resulted from the policy of biocontrol companies rather than from growers’ demands (For example: replacing of the coccinellid *Harmonia axyridis* with *Adalia bipunctata*).
Table 1. Introduction of natural enemies (numbers per m² per year) against aphids by organic growers at the beginning (2002) and the end (2006) of the project. * indicates use.

<table>
<thead>
<tr>
<th>Control agents</th>
<th>2002</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3  4  5  6  7  8</td>
<td>1  2  3  4  5  6  7  8</td>
</tr>
<tr>
<td>Aphidoletes aphidima</td>
<td>1.4 0.9 4.4 15 5 0.5 7.7</td>
<td>15 9.3 13 35 5 1.2</td>
</tr>
<tr>
<td>Aphidius colemani</td>
<td>6.1 1.1 0.9 13 3.3 18 8.6</td>
<td>10 9 5.5 38 15</td>
</tr>
<tr>
<td>Aphidius ervi</td>
<td>1.7 0.9 0.5 1.7 0.4 0.6 0.7 1.2</td>
<td>3.3 0.9 0.1 38 5.2</td>
</tr>
<tr>
<td>Aphiellus abdominalis</td>
<td>0.2 0.2 0.05 2.1</td>
<td>2.7 18 5.6</td>
</tr>
<tr>
<td>Hippodamia convergens</td>
<td>0.4 0.01 0.3 2.9</td>
<td>0.4</td>
</tr>
<tr>
<td>Harmonia axyris</td>
<td>0.04 2.1 0.8 0.5 0.6 0.5</td>
<td>0.3 0.9 0.03 0.3 0.6</td>
</tr>
<tr>
<td>Chrysoperla carnea</td>
<td>0.04 2.1 0.8 0.5 0.6 0.5</td>
<td>0.3 0.9 0.03 0.3 0.6</td>
</tr>
<tr>
<td>Epiusyrhus balteatus</td>
<td>0.04 2.1 0.8 0.5 0.6 0.5</td>
<td>0.3 0.9 0.03 0.3 0.6</td>
</tr>
<tr>
<td>Lysiphlebus</td>
<td>0.04 2.1 0.8 0.5 0.6 0.5</td>
<td>0.3 0.9 0.03 0.3 0.6</td>
</tr>
<tr>
<td>Adalia bipunctata</td>
<td>0.04 2.1 0.8 0.5 0.6 0.5</td>
<td>0.3 0.9 0.03 0.3 0.6</td>
</tr>
<tr>
<td>Aphi-ervibank</td>
<td>0.04 2.1 0.8 0.5 0.6 0.5</td>
<td>0.3 0.9 0.03 0.3 0.6</td>
</tr>
<tr>
<td>Savona</td>
<td>0.04 2.1 0.8 0.5 0.6 0.5</td>
<td>0.3 0.9 0.03 0.3 0.6</td>
</tr>
<tr>
<td>Spruzi</td>
<td>0.04 2.1 0.8 0.5 0.6 0.5</td>
<td>0.3 0.9 0.03 0.3 0.6</td>
</tr>
</tbody>
</table>

During the annual meetings, the following issues were brought up:

- Preventive releases, starting immediately after planting
- Regular release of natural enemies, to be continued after the collapse of the aphid population
- Release rates
- Increased release rates proportional to the aphid population
- Increasing the frequency of releasing Aphidius colemani
- Hyperparasitisation of A. colemani
- Climate factors affecting the fragile adults of A. aphidima
- Aphid control with(out) A. aphidima
- Impact of soil condition on pest development
- Impact of climate conditions on pest development
- The use of insectary plants for nectar supply

Figure 1. Leaf incidence (%) of aphids and occurrence of natural enemies in 2005.
The results of intensive scouting are presented in Figure 1. Weekly releases of natural enemies started directly after planting. The release rates were raised with the increase of the aphid population from 0.5 to 10 natural enemies per m$^2$. *M. persicae* was present from the beginning. Braconid wasps (that is, their mummies) were the first natural enemies observed, but they did not stop further increase of the aphid population. The grower had to start cleaning the fruits in week 19. The aphid population collapsed in week 26, just when the grower was about to intervene by spraying. Apparently, predation by cecidomyiid larvae was the key factor. The increase of braconids after this event as suggested by Figure 1 is probably just a relative phenomenon (fewer hosts). *Episyrphus balteatus* appeared in fluctuating numbers due to its long generation time. *Chrysoperla carnea* did not establish. The general picture was considered representative for the whole group of organic growers.

**Conclusions and discussion**

Ecological greenhouse growers have adopted a more preventive biological control strategy, introducing natural enemies of aphids more frequently and in higher numbers. As a result, they could reduce repairing sprays with natural pyrethrum. The net effect is an increase of their plant protection costs. Ecological growers accept these costs, because intervening with botanical insecticides, though it is within the regulations, still conflicts with the philosophy behind organic farming.

The main pest control problem, however, has not been solved for these growers. They still have to clean the fruits, and occasionally suffer severe yield losses, particularly in case of *A. solani*. The quality of completely biological aphid control continues to be unacceptable for mainstream (IPM) growers.

The area of organic vegetable production in greenhouses increased from 48 ha in 2004 to 82 ha in 2008. Although the ministerial program was aimed at persuading growers to switch over to organic production, few growers did. The increase observed is mainly caused by existing organic growers expanding their greenhouses.

With the current state of affairs, further investing in technology transfer projects seems to make little sense without first developing better control methods. Current research proposals focus on:

- improving the use of banker plant systems
- compatibility of natural enemies (food web interactions)
- impact of climatic conditions
- insectary plants for nectar supply
- effects of environmental factors on the performance of gall midge adults

**Reports consulted**


Potential of alternative prey in the conservation and establishment of *Orius insidiosus* (Say) (Hemiptera: Anthocoridae)

Vanda H.P. Bueno, Lívia M. Carvalho, Alessandra R. Carvalho
Laboratory of Entomology, Department of Entomology, Federal University of Lavras, P. O. Box 3037, 37200-000 Lavras, Minas Gerais, Brazil, E-mail: vhpbueno@ufla.br

Abstract: *Orius* species can be found in both managed and natural ecosystems, mainly in association with thrips. The objective of this study was to evaluate *O. insidiosus*’ biological parameters using the thrips *Frankliniella insularis* and *Spodoptera frugiperda* eggs as prey, as well as its predatory capacity on *S. frugiperda* eggs and adults of *Haplothrips gowdeyi* + *Frankliniella* sp. The experiment was conducted in a climatic chamber at 25 ±1°C, RH 60 ±10%, and a 15-h photophase. *O. insidiosus* development lasted longer when *S. frugiperda* eggs were used as food (13.0 days), as compared with *F. insularis* (10.4 days). During the nymphal stage, *O. insidiosus* consumed significantly more thrips (58.1 adults) when compared with *S. frugiperda* eggs (34.6 eggs). Females fed thrips laid a greater number of eggs (80.7 eggs/female) as compared to females fed *S. frugiperda* eggs (25.8 eggs/female). Thrips were more suitable for *O. insidiosus* development and reproduction, and may contribute toward the conservation and establishment of this predator in agroecosystems located neighbouring of greenhouses.

Key words: establishment, predator, development, reproduction, *Orius*

Introduction

The pursuit of sustainable agricultural systems is today a worldwide concern. Within this context, research has been conducted in order to increase agroecosystem diversification as a pest management strategy, since diversified agroecosystems provide favourable conditions for the establishment, conservation, and reproduction of natural enemies. According to van Lenteren (2000), this practice can be used even in protected cultivations, where many parasitoids and predators that occur naturally in the field may migrate into the greenhouse and become established in that environment.

In Brazil, relay cropping and/or intercropping have been used to reduce pests by increasing natural enemy populations, with positive results in several crops. In Europe, the use of banker plants has been a common practice in protected cultivations, and allows natural enemies to be constantly present in greenhouses, consuming alternative prey.

The omnivorous nature of predators in the genus *Orius* is considered an adaptive strategy that maintains their populations in the environment, allowing them to become established on the crop before the pests. In Brazil, the species *Orius insidiosus* (Say) is the most common and abundant of that genus (Bueno, 2005). Silveira et al. (2005) observed that the predator occurred simultaneously with 13 species of thrips on cultivated plants such as corn, as well as on spontaneous plants, indicating that they are possibly responsible for maintaining the predators in the ecosystems.

In order to acquire greater knowledge for the conservation and establishment of *O. insidiosus* in agroecosystems that exist around greenhouses, this study aimed to evaluate the biological aspects and predatory capacity of this predator, using both thrips present on spontaneous plants and *Spodoptera frugiperda* eggs (an important pest in corn crops) as prey.
Material and methods

The experiment was conducted in a climatic chamber adjusted at 25 ±1ºC, RH 60 ±10%, and a 15-h photophase. The predators and eggs of the noctuid *S. frugiperda* employed in the experiment came from laboratory colonies (DEN/UFLA). The thrips were selected because of their natural occurrence on spontaneous plants present in the field.

Development and reproduction of *O. insidiosus* on different prey

Forty freshly hatched *O. insidiosus* nymphs were individualized and fed adults and nymphs of the thrips *F. insularis* or *S. frugiperda* eggs. Evaluations included duration and survival of the various instars.

Mated females of *O. insidiosus*, up to 24 hours of age, were maintained in the presence of Bidens pilosa L. stems as oviposition substrate; the same prey types were provided as food. The pre-oviposition period, daily number, and total number of eggs per female were evaluated for each prey type. All parameters evaluated were submitted to analysis of variance and, when significant, the means were submitted to Tukey's test at 5% significance.

Feed intake of *O. insidiosus* on different prey

Prey intake by the *O. insidiosus* nymphs was evaluated starting at the second instar, by individualizing 10 nymphs of the predator for each prey type tested. For *S. frugiperda* eggs, 10 eggs glued onto filter paper strips were offered daily to each nymph; eggs whose contents were completely or partially sucked were considered predated. When thrips were used as prey, each nymph of the predator was offered 15 adults of Haplothrips gowdeyi + Frankliniella sp. daily, collected on pigeon pea plants (*Cajanus cajan*).

Ten males and 10 females of the predator up to 24 h of age were used to evaluate feed intake in the adult stage. Daily, each predator was offered 20 *S. frugiperda* eggs glued onto paper strips or twenty adults of *H. gowdeyi* + *Frankliniella* sp. as prey. Counts were obtained daily for number of prey consumed at all stages of nymphal development and at the adult stage of *O. insidiosus*. The data were submitted to analysis of variance and, when significant, the means were evaluated by Tukey's test at 5% significance.

Results and discussion

Development and reproduction of *O. insidiosus* on different prey

*O. insidiosus* completed its development feeding on both prey, *F. insularis* and *S. frugiperda* eggs. However, the diet offered affected nymphal development (Table 1). Although Silveira et al. (2005) did not observe a significant interaction between *O. insidiosus* and *F. insularis* present on plants in the field, both species were associated with each other. Based on the survival observed in this laboratory study, it is likely that this thrips species is an alternative prey for this predator under field conditions. The thrips *F. insularis* is frequently found on corn crops as well as on spontaneous plants.

As to adults, no difference (P>0.05) was observed between the pre-oviposition period of *O. insidiosus* fed *F. insularis* (2.4 days) or *S. frugiperda* eggs (2.1 days). However, *O. insidiosus* females fed *F. insularis* showed higher (P<0.05) daily numbers (4.9) and total numbers of eggs/female (80.7 eggs) when compared with females fed *S. frugiperda* eggs (1.6 and 25.8 eggs, respectively). Mendes et al. (2002) observed greater *O. insidiosus* fecundity when the females were fed *A. kuehniella* eggs (195.3 eggs/female) than when they were fed *Aphis gossypii* (20.0 eggs/female) or *Caliothrips phaseoli* prey (70.0 eggs/female). The results emphasize the influence of the nutritional composition of the prey tested on the biological
aspects of *O. insidiosus*. Foods, as well as temperature, constitute limiting factors for the development and reproduction of *Orius* species. This knowledge may be useful in studies on the mass rearing and conservation of the predator.

Table 1. Development (days) and survival (%) of *Orius insidiosus* reared on different prey at 25 ±1°C, RH 60 ±10%, 15-h photophase.

<table>
<thead>
<tr>
<th>Development period</th>
<th>Spodoptera frugiperda eggs</th>
<th>Frankliniella insularis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duration (days) Survival (%)</td>
<td>Duration (days) Survival (%)</td>
</tr>
<tr>
<td>1st instar</td>
<td>2.2b 95.0</td>
<td>1.2a 75.0</td>
</tr>
<tr>
<td>2nd instar</td>
<td>1.7a 81.5</td>
<td>1.3a 92.5</td>
</tr>
<tr>
<td>3rd instar</td>
<td>1.8b 87.1</td>
<td>1.0a 80.0</td>
</tr>
<tr>
<td>4th instar</td>
<td>1.1a 88.8</td>
<td>1.0a 100.0</td>
</tr>
<tr>
<td>5th instar</td>
<td>1.3a 91.6</td>
<td>1.2a 97.5</td>
</tr>
<tr>
<td>Nymph Period</td>
<td>13.0b 55.0</td>
<td>10.4a 55.0</td>
</tr>
</tbody>
</table>

*Means followed by the same letter in the row do not differ significantly from each other by Tukey’s test (P≤0.05).

Feed intake of *O. insidiosus* on different prey
A greater (P<0.05) intake of *H. gowdeyi + Frankliniella* sp. thrips was observed in all instars of the predator, when compared with the consumption of *S. frugiperda* eggs (Figure 1). Tommasini *et al.* (2004) verified that some species of *Orius* showed increased predation from the 1st to the 5th instar when preying on *E. kuehniella* eggs and *F. occidentalis* adults. The same was observed by Mendes *et al.* (2002) using *C. phaseoli* adults and *E. kuehniella* eggs as prey. These authors suggested that the difference in prey intake is related to the nutritional quality of each prey type. According to Price *et al.* (1980), herbivore susceptibility to natural enemies is often related to the nutritional quality of the plants on which the herbivores fed. This fact was confirmed by Brown *et al.* (1999), who observed that thrips predation level by *O. laevigatus* varied according to the plant species where the prey fed.

Plants that shelter the thrips species *Frankliniella* sp. and *H. gowdeyi* may encourage *O. insidiosus* conservation by supplying shelter, food (pollen), and alternative prey. Pinent *et al.* (2005) found *F. insularis* in the inflorescence and internal parts of five different plants, especially *Dioclea violacea* (Fabacea), a plant native to Brazil, popularly known as *olho-de-boi* (bulls-eye or wadra). Species of the genera *Haplothrips* and *Frankliniella* were found on *Cordia verbenacea* (Boraginaceae), popularly referred to as cordia or erva-baleeira. Colonization of plant habitats (e.g., crop systems) by natural enemies may be influenced by the proximity of the source of colonizers. Alternative prey in habitats with different plant communities and phenologies (e.g., spontaneous vegetation) can support predator populations when the prey becomes scarce in a given habitat. Such alternative habitats may then be a source of predatory bugs, like *Orius*, that colonize nearby crops (Coll, 1999).

This knowledge opens up new perspectives for future studies, particularly with regard to an adequate management of plants that may occur around greenhouses, both cultivated and spontaneous, in order to encourage the conservation and establishment of *O. insidiosus* and to promote greater effectiveness of thrips biological control programs in protected cultivations in Brazil.
Figure 1. Mean consumption of prey per instar and total numbers per *O. insidiosus* reared on different types of prey at 25 ±1°C, RH 60 ±10%, 15-h photophase. *Bars with different letters indicate statistically different values by Tukey's test (P ≤ 0.05).

**Acknowledgments**

The authors thank CNPq for scholarships awarded and for financial support to the study.

**References**


Intra-guild predation between *Amblyseius swirskii* (Athias-Henriot) and *Neoseiulus cucumeris* (Oudemans) (Acari: Phytoseiidae)

Rosemarije Buitenhuis1,2, Les Shipp2, Cynthia Scott-Dupree1
1University of Guelph, Environmental Biology Department, Guelph, Ontario, N1G 2W1, Canada, E-mail: buitenhuisr@agr.gc.ca; 2Greenhouse and Processing Crops Research Centre, Agriculture and Agri-Food Canada, 2585 County Road 20 RR2, Harrow, Ontario, N0R 1G0, Canada

**Abstract:** The relationships between the predatory mites, *Amblyseius swirskii* (Athias-Henriot) and *Neoseiulus cucumeris* (Oudemans), and their prey, western flower thrips (*Frankliniella occidentalis* Pergande), were investigated to determine the effects of predation on intra-guild or extra-guild prey. Life history characteristics of both predatory mites were measured when fed eggs and larvae of the other predator species, and compared to data obtained when the predators were fed thrips larvae. In addition, choice tests were conducted to determine if the predators had a preference for any of the different prey or if they were indiscriminate predators.

**Key words:** Phytoseiidae, prey preference, intra-guild interactions, biological control, greenhouse crops

**Introduction**

Pest suppression in greenhouse crops is often accomplished using several species of natural enemies at the same time. Biological control agents, such as polyphagous phytoseiid mites, have overlapping food ranges and compete for the same food source. In addition, they are also likely to engage in intra-guild interactions with each other (Yao & Chant, 1989; Schausberger & Walzer, 2001), which may or may not influence pest control (Rosenheim & Harmon, 2006).

*Amblyseius swirskii* (Athias-Henriot) (Acari: Phytoseiidae) is a relatively new predator for whitefly and thrips control in greenhouse crops. It is a generalist predator and can also predate on other insect and mite species. This broad host range is advantageous because *A. swirskii* could be used to control multiple pest species in the greenhouse. However, this could also be a problem if *A. swirskii* is predating on other biological control agents in the greenhouse.

In some greenhouse crops, e.g. peppers, cucumber and gerbera, growers release both *A. swirskii* and *Neoseiulus cucumeris* (Oudemans) (Acari: Phytoseiidae). It has been observed that plots of greenhouse cucumber to which *N. cucumeris* had been applied were colonized by *A. swirskii*, resulting in total decimation of the *N. cucumeris* population (Messelink et al., 2005).

It is not known if *A. swirskii* has intra-guild interactions with *N. cucumeris* and, if so, what the predation rate is. Intra-guild interactions are likely to be more important if the predator has a preference for intra-guild prey and if the quality of intra-guild prey as a food source is high. Therefore, in this study we investigated 1) the oviposition and predation rates of *A. swirskii* and *N. cucumeris* when fed intra-guild or extra-guild prey; and 2) *A. swirskii* and *N. cucumeris* prey preference in choice experiments.
Material and methods

Thrips and predatory mite rearing
A greenhouse colony of western flower thrips, *F. occidentalis*, was maintained on potted chrysanthemum (*Dendranthema grandiflora* Tzvelev, var. Chesapeake). Cohorts of thrips larvae were reared on kidney bean (*Phaseolus vulgaris* L.) leaves embedded in 1.5% (w/v) agar in 9-cm Petri dishes with screened lids in a controlled environmental chamber (25°C ± 1, RH 70% ± 10, L:D 12:12). Twenty five female thrips were allowed to oviposit on the leaf for 2 days. First instar larvae were obtained after 4 days (Robb, 1989).

Laboratory colonies of predatory mites were established using *A. swirskii* and *N. cucumeris* from Biobest Canada Ltd. (Leamington, ON, Canada). *Amblyseius swirskii* was reared according to methods adapted from Overmeer (1985) on bean leaf disks that were placed upside down on water saturated sponges in 237 ml containers (Solo, Highland Park, IL, USA), which were closed with a screened lid. Mites were fed every other day with cattail pollen (*Typha* sp.). Eggs were collected every day to create cohorts of a known age (<24 h). A colony of *N. cucumeris* was maintained on *Tyrophagus putrescentiae* (Schrank) (Acari: Acaridae) on wheat bran. To obtain cohorts of *N. cucumeris*, adult females were collected from the colony and held on leaf disks with cattail pollen. To obtain evenly aged mite cohorts, eggs were collected and reared on pollen as described above for *A. swirskii*.

Predation and oviposition capacity
To investigate the effects of eating intra-guild or extra-guild prey, *A. swirskii* and *N. cucumeris* females (2-4 days old) were provided with prey ad libitum for 4 days. Predation and oviposition capacity of both predatory mite species were measured when fed eggs, larvae or deutonymphs of the other predator species, and compared to data obtained when the predators were fed thrips larvae. One female mite was confined on a leaf disk (1.5 × 1.5 cm) that floated upside down on a water saturated sponge in a 60 ml cup (Solo, Highland Park, IL, USA). The cup was closed with fine mesh screening held in place by a lid with a 2 cm wide hole. Cups were placed in a controlled environmental chamber (25°C ± 1, RH 70% ± 10, L:D 16:8). Prey was renewed every day (10 eggs, 15 larvae, 10 deutonymphs, 10 first instar thrips). Trials were replicated 8-15 times. Data from the first day were omitted from the calculations of predation and oviposition capacity to reduce the influence of pre-experimental conditions. Data were square root transformed and comparisons were made among prey and between mite species using two-way ANOVA.

Choice experiments
Choice tests were conducted to determine if the predators had a preference for any prey species, or life stage, or if they predated indiscriminately. Female *A. swirskii* (2-4 days old) were individually put on leaf disks and given abundant prey of two prey species/stages for 2 days (5 *N. cucumeris* eggs + 15 *N. cucumeris* larvae; 5 *N. cucumeris* eggs + 10 first instar thrips; 15 *N. cucumeris* larvae + 10 first instar thrips). Data from the first day were omitted to reduce the influence of pre-experimental conditions. As an indiscriminate predator, it would be expected that the mite would eat half the amount of both prey types as measured in the experiment on predation capacity. This comparison was made using a t-test. It was not possible to perform the same experiment for *N. cucumeris* females, because the *A. swirskii* larvae quickly molted to protonymphs which fed on the thrips and eggs, confusing the results.

In addition, female *A. swirskii* and *N. cucumeris* mites were observed when given the choice between one of each of two prey species/stages (*N. cucumeris* egg vs. *N. cucumeris* larva; *N. cucumeris* egg vs. first instar thrips; *N. cucumeris* larva vs. first instar thrips). A
single female mite (2-4 days old) was given a 1 day exposure period to abundant prey of two prey species/stages and then starved for the next day. On the third day, the female was confined on a small leaf disk (0.5 × 0.5 cm) with one of each of two prey species/stages and her behaviour was observed and timed until the mite made a choice and started feeding.

**Results and discussion**

**Predation and oviposition capacity**

Both *A. swirskii* and *N. cucumeris* predated on each other, and immature stages were most vulnerable (Table 1). Adult stages did not feed on each other (data not shown). Both predators were observed to have difficulties piercing eggs with their mouthparts, so eggs were only predated in small numbers, as was found for other phytoseiid mites (Schausberger & Croft, 1999). Comparing the two predators, *A. swirskii* had a higher predation rate of intra-guild prey than *N. cucumeris*, but *N. cucumeris* consumed more thrips than *A. swirskii* (Table 1). Similarly, *A. swirskii* had a higher oviposition rate on intraguild prey eggs and deutonymphs, but *N. cucumeris* laid more eggs when it was fed on thrips (Table 2). Comparing prey within species, *A. swirskii* had a higher oviposition rate on *N. cucumeris* larvae and deutonymphs than on thrips, which indicates that mite immatures are the better food source for this predator (Table 2). In contrast, oviposition by *N. cucumeris* was the same on both thrips and *A. swirskii* immatures. Oviposition rates of both predator species on eggs were the lowest.

Table 1. Daily predation rate (mean ± SE) of *Amblyseius swirskii* and *Neoseiulus cucumeris* on western flower thrips and intra-guild prey. Values in columns and rows followed by the same letter are not significantly different (two-way ANOVA).

<table>
<thead>
<tr>
<th></th>
<th>Thrips</th>
<th>Intra-guild prey</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>First instar</td>
<td>Eggs</td>
<td>Larvae</td>
<td>Deutonymphs</td>
</tr>
<tr>
<td><em>A. swirskii</em></td>
<td>4.0 ± 0.3 c</td>
<td>2.0 ± 0.5 b</td>
<td>11.4 ± 0.3 g</td>
<td>7.0 ± 0.4 ef</td>
<td></td>
</tr>
<tr>
<td><em>N. cucumeris</em></td>
<td>5.8 ± 0.8 de</td>
<td>0.7 ± 0.1 a</td>
<td>7.8 ± 0.3 f</td>
<td>4.5 ± 0.3 cd</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Daily oviposition rate (mean ± SE) of *Amblyseius swirskii* and *Neoseiulus cucumeris* on western flower thrips and intra-guild prey. Values in columns and rows followed by the same letter are not significantly different (two-way ANOVA).

<table>
<thead>
<tr>
<th></th>
<th>Thrips</th>
<th>Intra-guild prey</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>First instar</td>
<td>Eggs</td>
<td>Larvae</td>
<td>Deutonymphs</td>
</tr>
<tr>
<td><em>A. swirskii</em></td>
<td>1.4 ± 0.2 bc</td>
<td>1.2 ± 0.2 b</td>
<td>2.1 ± 0.1 e</td>
<td>2.1 ± 0.2 e</td>
<td></td>
</tr>
<tr>
<td><em>N. cucumeris</em></td>
<td>2.0 ± 0.2 de</td>
<td>0.8 ± 0.1 a</td>
<td>1.9 ± 0.2 cde</td>
<td>1.5 ± 0.2 bcd</td>
<td></td>
</tr>
</tbody>
</table>

**Choice experiments**

In choice experiments, *A. swirskii* preferred to prey on *N. cucumeris* larvae than on thrips larvae (Table 3). Eggs of *N. cucumeris* were the least preferred prey. The observations on prey choice confirmed these results. In contrast, *N. cucumeris* had no preference between *A. swirskii* eggs and larvae or *A. swirskii* eggs and thrips larvae (Table 3). However, like *A. swirskii*, *N. cucumeris* preferred to prey on intra-guild prey larvae rather than on thrips larvae. This choice might be influenced by the defence behaviour of thrips larvae.
Based on these results, *A. swirskii* appears to be a serious intra-guild predator of *N. cucumeris* because of a high predation rate and a preference for *N. cucumeris* larvae over thrips. *Neoseiulus cucumeris* is also an intra-guild predator of *A. swirskii*, however, it has a lower predation rate than *A. swirskii*. These results will be used to develop IPM recommendations for these predatory mites in ornamental greenhouse situations.

Table 3. Predation rate (1 day) of *A. swirskii* and *N. cucumeris* presented with two prey species/stages (mean ± SD), and separate trial on observations on prey choice (prey 1: prey 2).

<table>
<thead>
<tr>
<th></th>
<th>Prey 1</th>
<th>Prey 2</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>A. swirskii</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>N. cucumeris</em> eggs vs thrips first instar</td>
<td>1.7 ± 0.3 ns¹</td>
<td>3.9 ± 0.3 *</td>
<td>0:6</td>
</tr>
<tr>
<td><em>N. cucumeris</em> larvae vs thrips first instar</td>
<td>9.1 ± 0.5 *</td>
<td>2.2 ± 0.3 ns</td>
<td>6:1</td>
</tr>
<tr>
<td><em>N. cucumeris</em> eggs vs <em>N. cucumeris</em> larvae</td>
<td>0.7 ± 0.2 ns</td>
<td>10.7 ± 0.5 *</td>
<td>2:5</td>
</tr>
<tr>
<td><em>N. cucumeris</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>A. swirskii</em> eggs vs thrips first instar</td>
<td>-</td>
<td>-</td>
<td>4:5</td>
</tr>
<tr>
<td><em>A. swirskii</em> larvae vs thrips first instar</td>
<td>-</td>
<td>-</td>
<td>7:1</td>
</tr>
<tr>
<td><em>A. swirskii</em> eggs vs <em>A. swirskii</em> larvae</td>
<td>-</td>
<td>-</td>
<td>6:5</td>
</tr>
</tbody>
</table>

¹T-test compared to expected results if indiscriminate predator (1/2 values in Table 1); ns: not significant; *: significantly different at $\alpha=0.05$.

**Acknowledgements**

We thank Wonhyo Lee and Yun Zhang for technical assistance. This research was supported by Flowers Canada (Ontario) and the Matching Investment Initiative of Agriculture and Agri-Food Canada.

**References**


Release rates of *Orius insidiosus* to control *Frankliniella occidentalis* on protected potted gerbera

Alessandra R. Carvalho, Vanda H.P. Bueno, Alexa G. Santana, Nazarê Moura, Elaine A. Louzada
Laboratory of Biological Control, Department of Entomology, Federal University of Lavras, P.O. Box 3037, 37200-000 Lavras, MG, Brazil, E-mail: acarvalho@ufla.br, vhpbueno@ufla.br

**Abstract:** Reductions of *Frankliniella occidentalis* populations using *Orius insidiosus* were obtained in several ornamentals, such as saintpaulia, impatiens, and gerbera. The purpose of this study was to determine the action of this predator on the biological control of the thrips *F. occidentalis* after different release rates under a commercial protected cultivation area of potted gerbera. The experiment was conducted during the entire cultivation cycle, for a total of 16 weeks. The population dynamics of *F. occidentalis* was evaluated in two areas located in different greenhouses, one with releases of the predator (20 m²) and the other with the use of chemical control (25 m²). Eight releases of *O. insidiosus* adults + nymphs were performed, ranging from 0.15 to 1.20 *O. insidiosus* per gerbera pot. It was observed that under a release rate of 1.20 *O. insidiosus*/pot, the *F. occidentalis* population reached numbers that were lower (varying from 20 to 80%) than those observed in the area where chemical control was applied. *O. insidiosus* predators were found on the gerbera plants up to two weeks after they were released. The use of *O. insidiosus* to control thrips in commercial gerbera crops is promising; however, additional adjustments are needed with regard to release rates and frequencies.

**Key words:** predators, thrips, ornamentals

**Introduction**

Brazilian commercial floriculture initially developed in the State of São Paulo, but today it can be found in practically all states of Brazil. The great diversity and amplitude of climates and soils found in Brazil allow the cultivation of many species of flowers and ornamental plants from various origins (native, temperate climate, and tropical), with potential to compete in the international market. In the State of Minas Gerais, floriculture occupies an area of 118 ha, of which 18 ha are cultivated in greenhouses (Cançado Jr. *et al.*, 2005). The cultivation of gerbera (*Gerbera jamesonii* Adlam) (Compositae) occurs in the central and southern regions of the state.

Pests are a serious problem for cut and potted flowers. Thrips are considered the biggest problem during the flowering stage of gerbera, causing aesthetic damages and making flowers unsuitable for sale. In gerbera, as well as in chrysanthemum, these pests cause deformations on growing parts and flowers, or silver lesions, resulting in distorted petals, discoloration, and streaks (Bueno, 2005).

Insecticides have limited effectiveness due to the pest's cryptic habit, in addition to severe resistance problems. However, although biological control has not yet been implemented in Brazil, it is a practice that yields satisfactory results in countries of Europe and North America. A good example is gerbera - in the Netherlands > 40% is under IPM (van Lenteren, 1995) - and trend information is especially useful in determining the efficacy of a
control measure that has been applied. Thus, our research was directed towards anthocorid predators of the genus *Orius*, the most promising category of *F. occidentalis* predators.

This study aimed to determine the action of various release rates of *O. insidiosus* on the reduction of *F. occidentalis* populations in gerberas grown in commercial greenhouses.

**Material and methods**

The experiment was conducted in a commercial planting of potted gerbera grown in greenhouses in the city of Lavras, Minas Gerais, Brazil, during the period from July to October 2006, totalling 16 weeks. Two areas in different greenhouses were used, one measuring 25 m² (380 pots/week on average) with the use of conventional chemical control of insects and diseases, and the other measuring 20 m² (300 pots/week on average) in which control consisted of releases of the predator *O. insidiosus* alone.

Thirty gerbera pots were sampled weekly per area, by beating the flowers (tapping method) over a sheet of white paper, and counts were obtained for thrips and *Orius* predators. The specimens were placed in 70% alcohol for later confirmation of the species involved.

Eight releases of adults + nymphs of *O. insidiosus* were performed during the 16-week period; the number of *O. insidiosus*/gerbera pot/release was progressively increased as the cropping cycle advanced, ranging between 0.15 and 1.20 *Orius*/gerbera pot (Table 1).

Table 1. Release rates of *Orius insidiosus*/gerbera pot in each release of the predator in a commercial greenhouse.

<table>
<thead>
<tr>
<th>Release</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Release date (year: 2006)</td>
<td>07/06</td>
<td>07/13</td>
<td>07/20</td>
<td>08/03</td>
<td>08/17</td>
<td>09/06</td>
<td>10/05</td>
<td>10/26</td>
</tr>
<tr>
<td>No. of <em>O. insidiosus</em>/pot</td>
<td>0.15</td>
<td>0.24</td>
<td>0.36</td>
<td>0.45</td>
<td>0.78</td>
<td>1.20</td>
<td>1.20</td>
<td>0.97</td>
</tr>
</tbody>
</table>

**Results and discussion**

Although the populations of the thrips *F. occidentalis* were low and similar in numbers in the beginning of the evaluations (Figure 1) in both gerbera areas, the number of *O. insidiosus* released in the first three weeks of the cropping cycle (0.15; 0.24; and 0.36 predators/gerbera pot) was not sufficient to maintain the thrips population at low levels in the biological control area; increasingly higher numbers of the *F. occidentalis* population were observed until the seventh week (Figure 1). In addition, the increased numbers of *O. insidiosus* released on the fifth week of the cropping cycle (0.45/gerbera pot) were not sufficient to deter the population increase of *F. occidentalis*.

The best result for the action of the predator *O. insidiosus* on the population of the prey *F. occidentalis* was obtained when 1.20 *O. insidiosus*/gerbera pot were released on the seventh and ninth weeks (Figure 1). Reductions of *F. occidentalis* populations using *O. insidiosus* were also obtained in gerbera, in experiments conducted by Sorensson and Nedstam (1993). The control of thrips in commercial gerbera by *O. insidiosus* is feasible when some (second class) flowers are kept in the crop to provide pollen (Ravensberg & Altena, 1993).

Silveira et al. (2004) used 1.5 to 2.0 *O. insidiosus*/m² in a cut chrysanthemum area in Brazil, which would be equivalent to 0.09 to 0.13 *Orius*/gerbera pot (1m² = 16 gerbera pots), achieving effective thrips control in chrysanthemum. However, by comparing the release rates in our experiment with the results presented by Silveira et al. (2004), it can be seen that
growing ornamentals in pots requires a much higher number of natural enemies than the numbers used with ornamentals produced directly on the soil, probably due to smaller plant densities/m²; i.e., the space that exists between the pots may have made it harder for the biological control agents to move from pot to pot, reducing their dispersal.

Release rates should always be taken into consideration; according to van Lenteren and Tommasini (1999) determining the numbers of insects released, as well as the distribution and frequency of releases are very difficult problems. In greenhouses, resurgence of pests is likely to occur and represents a serious threat. In these seasonal inoculative release programs, release ratios are usually determined by trial and error, but according to van Lenteren & Tommasini (1999) the first simulation programs are just being launched for a more scientific estimate of release rates (number of releases, spacing between release points, and timing of releases).

It was observed that in the area where chemical control was used, consisting of sprays with non-selective products under the conventional system, the *F. occidentalis* population was maintained at numbers below 20 thrips/gerbera pot in 15 out of the 16 weeks the cropping cycle lasted (Figure 1), which prevented the appearance of damage symptoms on the plants. However, during four weeks or 25% of the cropping cycle period, the *F. occidentalis* population was 20 to 80% smaller in the area where *O. insidiosus* was released than the *F. occidentalis* population observed in the area where chemical control was used (Figure 1). This was observed when the release rate of the predator *O. insidiosus* was 1.20 *Orius*/gerbera pot, which, in comparative terms, could mean savings in labour, materials, and time. Based on the cost for the production of *O. insidiosus* in Brazil, US$0.07/individual according to Mendes et al. (2005), control for each gerbera pot would cost US$0.08. In view of these figures, it can be said that the cost of each *O. insidiosus* release in the study area was around US$31.87, or US$255.00 in the four-month cropping cycle period.

![Figure 1. Population fluctuation of *Frankliniella occidentalis* in a commercial planting of *Gerbera jamesonii*, controlled with releases of *Orius insidiosus* or with chemical products.](image)

Releases of *Orius insidiosus*.

Aesthetic damages could be observed in the plants starting at 25 thrips/gerbera pot, which indicates that the injury level is around this threshold, i.e., control must be adopted before the population of the pest reaches this number to prevent aesthetic losses in the production. Some thrips damage thresholds have been published; however, thresholds are very sensitive to the
particular conditions at hand, including the crop, variety, local market standards, and very importantly, whether or not viruses are present at the site (van Driesche et al., 1998).

It must be pointed out that the high number of thrips/gerbera pot in the area where *O. insidiosus* was released was also caused by the presence and severe attack of *F. occidentalis* on ornamental pepper plants grown in the same greenhouse. These plants were a source of thrips and allowed their migration to the gerbera plants.

The presence of many gerbera plants with symptoms of attack of the leafminer *Liriomyza* sp. was observed in the area where chemical control was used. However, in the area where *O. insidiosus* was released a smaller number of gerbera plants showed leaves damaged by the leafminer; the presence of *Opius* sp. and *Diglyphus* sp. parasitoids was also observed, with natural action upon the pest.

Our results indicate that *O. insidiosus* was effective in reducing the *F. occidentalis* population in gerbera when released at the rate of 1.20 Orius/gerbera pot. The predator was capable of establishing and reproducing in the area where it was released, since nymphs and adults of *O. insidiosus* were found until two weeks after their release in gerbera plants. Therefore, the use of *O. insidiosus* to control thrips in commercial gerbera plantings in Brazil is promising; however, additional adjustments are needed with regard to release rates and frequencies.

**Acknowledgments**

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**References**


Storage of adults of two species of *Orius* (Hemiptera: Anthocoridae) at low temperature

Lívia M. Carvalho, Vanda H.P. Bueno, Alexandre J.F. Diniz, Alexa G. Santana

Laboratory of Biological Control, Department of Entomology, Federal University of Lavras, P.O. Box 37, 37200-000 Lavras, MG, Brazil, E-mail: vhpbueno@ufla.br

**Abstract:** Storage at low temperatures is an important step during the process of mass rearing and use of natural enemies, since it allows greater flexibility in the rearing, transport, and release of beneficial agents. In Brazil, biological studies have been conducted with different species of *Orius*. Their use in biological control programs against thrips is promising in many protected crops. This study aimed to evaluate the influence of storage periods at low temperatures on the reproductive capacity and longevity of the predators *Orius insidiosus* and *Orius thyestes*. It was observed that *O. insidiosus* is less sensitive to low temperatures; adults of this predator can be stored for up to 10 days at 8°C, while *O. thyestes* adults can be stored for up to 6 days at 12°C. These results may be helpful to plan the processes by which these predators are mass reared and transported to the sites where they should be released.

**Key words:** biological control, predators, mass-rearing

**Introduction**

Storage at low temperatures is an important step in the process of mass rearing and use of natural enemies in biological control programs of pests (van Lenteren, 2003). According to van Lenteren and Tommasini (2003), progress in the area of mass production, quality control, storage, shipment, and release of natural enemies has decreased production costs, resulting in better quality products for consumers, making biological control simpler and economically more attractive.

Some of the most important natural enemies used to control thrips are predators in the genus *Orius*. In Brazil, biological studies have been conducted with different species of *Orius*, and their use in biological control programs against thrips is promising in many protected crops (Bueno, 2005) as chrysanthemum, gerbera, rose and strawberry. Thus, in order to make the use of these control agents a reality in the country, research must be conducted on mass-rearing optimization, and on the development of an effective storage system, since this will allow greater flexibility in the rearing, transport, and release of these beneficial agents. This study aimed to evaluate the influence of storage periods at low temperatures on the reproductive capacity and longevity of the predators *O. insidiosus* and *O. thyestes*.

**Material and methods**

The study was conducted at DEN/UFLA's biological control laboratory, Brazil. The *O. insidiosus* and *O. thyestes* adults used in the tests were reared according to the methodology proposed by Bueno (2000). Storage periods were 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 days at temperatures of 8 and 12°C, under continuous scotophase.

Three hundred *O. insidiosus* and *O. thyestes* adults aged up to 48 hours after emergence
(150 males and 150 females of each species) were individualised at each temperature in glass vials (2 × 8 cm) containing *Ephestia kuehniella* eggs as a food source, and moistened cotton to prevent desiccation. The glass vials were transferred to incubators adjusted to the temperatures under evaluation. After each storage period the numbers of live males and females in each temperature were counted. Then, ten males and ten females from each temperature were transferred to an air-conditioned room at 25 ±1°C, RH 70 ±10%, and a 12-hour photophase and maintained as pairs in glass vials (2 × 8 cm) containing *E. kuehniella* eggs as food and a farmer’s friend inflorescence (*Bidens pilosa*, L.) as oviposition substrate. The procedure by which adults were transferred to 25°C was then repeated every two days until a 20-day storage period was completed, at each temperature evaluated. Observations were made for the survival of *O. insidiosus* and *O. thyestes* males and females maintained at both temperatures, in addition to daily and total fecundity and adult longevity.

A completely randomized experimental design was used, under a 2 × 2 × 10 factorial combination (consisting of two species, two temperatures, and ten storage periods) with 10 replicates per treatment; each replicate consisted of one insect pair. An analysis of variance was run and, when significance was found, the means were submitted to Student's t-test at 5% probability.

### Results and discussion

The low temperatures affected the reproductive capacity and longevity of the predators evaluated. It was observed that *O. thyestes* was more sensitive to low temperatures; less than 50% of the adults stored survived at 8 and 12°C (Table 1). In addition, no *O. thyestes* adult survived more than 14 days when stored at either temperature. Carvalho *et al.* (2005) observed that lower temperatures were unfavourable to *O. thyestes* development and reproductive capacity.

*O. insidiosus* survival was above 70% at the temperatures evaluated (Table 1). As reported by van Lenteren and Tommasini (2003) most predators can be stored for short periods at temperatures ranging between 4 and 15°C. According to Association of Natural Biocontrol Producers (ANBP) (2002), the predator *O. insidiosus* can be maintained for a few days at 10°C, but survival and oviposition decrease as the cold storage period increases.

Table 1. Survival (%) of *Orius insidiosus* and *Orius thyestes* adults maintained at low temperatures and continuous scotophase for different storage periods, and then transferred to 25 ±1°C, RH 70 ±10% and a 12h photophase.

<table>
<thead>
<tr>
<th>Sex</th>
<th>8°C</th>
<th>12°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>O. insidiosus</em></td>
<td><em>O. thyestes</em></td>
</tr>
<tr>
<td>Female</td>
<td>77.6</td>
<td>44.1</td>
</tr>
<tr>
<td>Male</td>
<td>70.4</td>
<td>44.3</td>
</tr>
</tbody>
</table>

The highest fecundity of *O. thyestes* (2.0 eggs/female/day) was observed at 12°C, after storage for 6 days (Table 2). Higher total fecundity (60 eggs/female) and daily fecundity (4.1 eggs/female/day) were observed for *O. insidiosus* when the females were stored for 10 days at 8°C (Table 2). van Lenteren *et al.* (2003) recommend as guidelines quality control standard a fecundity greater of the 30 eggs per female per 14 days.
Table 2. Daily fecundity per female (± SE) of *Orius insidiosus* and *Orius thyestes* maintained at low temperatures and continuous scotophase for different storage periods, and then transferred to 25 ±1°C, RH 70 ±10% and a 12h photophase.

<table>
<thead>
<tr>
<th>Storage (days)</th>
<th>8°C</th>
<th>12°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>O. insidiosus</em></td>
<td><em>O. thyestes</em></td>
</tr>
<tr>
<td>2</td>
<td>4.4 ± 0.50aA</td>
<td>1.2 ± 0.24aB</td>
</tr>
<tr>
<td>4</td>
<td>3.9 ± 0.29aA</td>
<td>0.8 ± 0.31aB</td>
</tr>
<tr>
<td>6</td>
<td>3.9 ± 0.50aA</td>
<td>1.1 ± 0.29aB</td>
</tr>
<tr>
<td>8</td>
<td>3.0 ± 0.64aA</td>
<td>0.7 ± 0.22aB</td>
</tr>
<tr>
<td>10</td>
<td>4.1 ± 0.57aA</td>
<td>0.8 ± 0.25aB</td>
</tr>
<tr>
<td>12</td>
<td>1.3 ± 0.37bA</td>
<td>0.7 ± 0.23aB</td>
</tr>
<tr>
<td>14</td>
<td>2.4 ± 0.46bA</td>
<td>0.1 ± 0.40aB</td>
</tr>
<tr>
<td>16</td>
<td>1.6 ± 0.41b</td>
<td>-</td>
</tr>
<tr>
<td>18</td>
<td>1.7 ± 0.37b</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>1.8 ± 0.50b</td>
<td>-</td>
</tr>
</tbody>
</table>

*Means followed by the same lower case letter in the column or upper case letter in the row, for each temperature, do not differ from each other by Student's t-test at 5% probability.

No significant differences were observed in *O. thyestes* longevity when maintained at 8 and 12°C and at the various storage periods evaluated (Table 3). The greatest *O. insidiosus* longevities (11.2 to 14 days) were observed when the adults were stored for up to 10 days at 8°C.

Table 3. Longevity (days) (± SE) of *Orius insidiosus* and *Orius thyestes* maintained at low temperatures and continuous scotophase for different storage periods, and then transferred to 25 ±1°C, RH 70 ±10% and a 12h photophase.

<table>
<thead>
<tr>
<th>Storage (days)</th>
<th>8°C</th>
<th>12°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>O. insidiosus</em></td>
<td><em>O. thyestes</em></td>
</tr>
<tr>
<td>2</td>
<td>11.2 ± 1.15a</td>
<td>11.2 ± 2.15a</td>
</tr>
<tr>
<td>4</td>
<td>10.6 ± 1.44a</td>
<td>10.0 ± 2.73a</td>
</tr>
<tr>
<td>6</td>
<td>12.0 ± 1.42a</td>
<td>11.2 ± 2.38a</td>
</tr>
<tr>
<td>8</td>
<td>13.4 ± 1.66a</td>
<td>9.6 ± 1.36a</td>
</tr>
<tr>
<td>10</td>
<td>14.0 ± 2.51a</td>
<td>7.4 ± 2.89a</td>
</tr>
<tr>
<td>12</td>
<td>9.4 ± 1.03b</td>
<td>6.2 ± 1.50a</td>
</tr>
<tr>
<td>14</td>
<td>7.4 ± 1.19b</td>
<td>6.2 ± 1.36a</td>
</tr>
<tr>
<td>16</td>
<td>8.8 ± 1.34b</td>
<td>-</td>
</tr>
<tr>
<td>18</td>
<td>8.6 ± 1.33b</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>9.0 ± 1.58b</td>
<td>-</td>
</tr>
</tbody>
</table>

*Means followed by the same letter in the column do not differ from each other by Student's t-test at 5% probability.
Smaller *O. insidiosus* sensitivity was observed at low temperatures. *O. insidiosus* adults can be stored for 10 days at 8°C, without compromising the predator's fecundity and longevity; however, *O. thyestes* adults can be stored for 6 days at 12°C.

The ability to store entomophagous agents for short periods is a key factor in developing the augmentative biological control method, since it will allow greater flexibility in the mass rearing and transport of these individuals, from the laboratory colony to the release site, and will facilitate exchanges between laboratories (van Lenteren, 2003). These results could be useful to help plan the processes by which these predators are mass reared and transported to their release sites. However, further studies are needed to evaluate the predatory capacity and effectiveness of these control agents under natural conditions after storage periods.

**Acknowledgments**

The authors thank to the agencies CNPq for granting scholarships and FAPEMIG for financial support to the project.

**References**


Control of *Frankliniella occidentalis* (Thysanoptera: Thripidae) on greenhouse roses with *Amblyseius* (*Typhlodromips*) *swirskii* (Athias-Henriot) (Acari: Phytoseiidae) and *Orius insidiosus* (Hemiptera: Anthocoridae)

Andrew Chow, Amanda Chau, Kevin M. Heinz
*Biological Control Laboratory, Department of Entomology, Texas A&M University, College Station Texas 77843-2475, US, E-mail: achow@tamu.edu*

**Abstract**: Despite the widespread use of insecticides, western flower thrips, *Frankliniella occidentalis* (Pergande), are still difficult pests to control on floriculture crops. As an alternative to chemical control, we evaluated the use of the predatory mite, *Amblyseius swirskii* (Anthias-Henriot), alone and together with the predatory bug, *Orius insidiosus* (Say), for suppressing *F. occidentalis* on cut roses. In greenhouse trials simulating thrips infestations of cut rose crops, we compared control of *F. occidentalis* on roses with releases of only *A. swirskii* or both *O. insidiosus* and *A. swirskii*. Roses with or without predators produced similar numbers of harvestable flowers, but roses without predators had, on average, two to three times more thrips than roses with predators. Concurrent releases of *O. insidiosus* with *A. swirskii* did not improve suppression of *F. occidentalis* on cut roses because counts of thrips on flowers with both *O. insidiosus* and *A. swirskii* were not statistically different from counts on flowers with only *A. swirskii*.

**Key words**: anthocorid, biological control, intraguild predation, predatory mite, western flower thrips

**Introduction**

A growing trend among biological control programs is to use two or more species of natural enemies to suppress populations of insect pests. Biological control programs for ornamental crops often use combinations of predators, parasitoids, or pathogens against agromyzid leafminers, aphids, thrips, and whiteflies. For practitioners of biological control, an important question is: will multiple predators suppress populations of pests more effectively than a single predator?

Chemical control for *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) on floriculture crops can be difficult because this pest has developed resistance to many insecticides and also tends to hide within flowers, buds, and apical meristems. *Amblyseius (= Typhlodromips) swirskii* (Athias-Henriot) (Acari: Phytoseiidae) has been highly recommended as a control agent for *F. occidentalis* on greenhouse crops and is commercially available in both Europe and North America (Messelink *et al*., 2006). *Amblyseius swirskii* can reach confined habitats preferred by *F. occidentalis* but kills primarily first-instar larvae. *Orius insidiosus* (Say) (Hemiptera: Anthocoridae) has also been used to control thrips, particularly in sweet pepper (van den Meiracker & Ramakers, 1991). This anthocorid preys on both larvae and adult thrips but has limited ability to attack thrips within confined plant parts. We were interested in whether use of both agents may improve control of thrips through complimentary predation. Our objective was to determine if suppression of *F. occidentalis* on greenhouse cut roses by inundative releases of *A. swirskii* could be enhanced by concurrent releases of *O. insidiosus*. 
Material and methods

Insects and plants
We maintained a colony of *F. occidentalis* on kidney bean (*Phaseolus vulgaris* L.) and purchased *O. insidiosus* and *A. swirskii* from Koppert Biological Systems Inc. (Romulus, MI, USA). Rose plants were grown from bare-root roses (*Rosa hybrida* L. cv. ‘Tropicana’, ‘Dr. Huey’ rootstock) individually planted in 14-l, plastic nursery-containers filled with soilless potting mix, pine bark mulch, and sand (3:1:1, by volume). The plants were cultivated as a cut flower crop in greenhouses on the Texas A&M University, College Station campus.

Control of *F. occidentalis* with *A. swirskii* and *O. Insidiosus*
Our trials were conducted in a research greenhouse from April to June 2006. We compared control of *F. occidentalis* by exposing roses to only *F. occidentalis*, *F. occidentalis* and *A. swirskii*, or *F. occidentalis* with both *A. swirskii* and *O. insidiosus*. The number of replications was three per treatment and each replicate consisted of twelve potted plants arranged in a 6-by-2 grid and confined within a thrips-proof, screened cage (120-inch long × 50-inch wide × 48-inch high). In each cage we released 32 adult females and 8 adult males of *F. occidentalis* twice each week over five consecutive weeks and then once each week over three consecutive weeks (total = 520 thrips over 13 releases per replicate). During the same week of the first thrips release (week 1), we hung a single sachet (Swirski-Mite Plus™) of *A. swirskii* near the centre of each potted plant in all replicates assigned predatory mites. Four weeks later, we replaced all the old sachets with new ones (week 5). To determine the release rate of *A. swirskii*, we used non-toxic putty to fix a single ‘monitor’ sachet onto the centre of a sticky card (5-inch L × 3-inch W) and placed one card within each replicate assigned predatory mites. Each week, we counted all the predatory mites captured on each card and replaced the old cards with new ones. Beginning one week after the first thrips releases (week 2), we released eight adult females and eight adult males of *O. insidiosus* each week over six consecutive weeks in all replicates assigned both predatory mites and anthocorids (total = 96 anthocorids over six releases per replicate). Starting two weeks after the first thrips were released (week 3), we harvested all shoots with flowers that opened recently. Flower shoots were harvested three times each week during the third to tenth weeks of the crop. We counted all stages of *F. occidentalis* and both predator species (except eggs) extracted from flower shoots harvested from each cage. Repeated-measures ANOVA was used to compare weekly counts of flowers, *A. swirskii* on sticky cards, and both thrips and predators from plants.

Results
Plants without predators and plants with predators produced similar numbers of open flowers each week (one-way repeated measures ANOVA: $F_{2,6} = 0.73; P = 0.52$) and started at $11.4 ± 0.8$ (n = 9; ± SE) in the first week, increased to $19.7 ± 1.2$ (n = 9; ± SE) by the third week, and declined to $15.0 ± 1.6$ (n = 9; ± SE) by the tenth week of the crop. We found significant differences between counts of *F. occidentalis* for flowers harvested from plants exposed to only thrips or both thrips and predators (one-way repeated measures ANOVA: $F_{2,6} = 25.53; P = 0.001$) (Figure 1), but there was no significant interaction between week and treatment (repeated measures two-way ANOVA: $F_{16,48} = 0.97; P = 0.47$). When pooled across weeks, thrips counts were two to three times higher for flowers from plants with no predators (back-transformed mean = 111.22) than for flowers from plants with only *A. swirskii* (back-transformed mean = 49.54) or both *A. swirskii* and *O. insidiosus* (back-transformed mean =
36.16). Suppression of \textit{F. occidentalis} was not significantly affected by the number of predators species released (Figure 1).

Numbers of \textit{A. swirskii} captured on sticky cards were similar for both predator treatments (one-way repeated measures ANOVA: $F_{1,4} = 1.49; P = 0.29$) and peaked during the second or third weeks of use but quickly declined by the fourth week (Figure 2). We estimated that around 500-700 predatory mites were released onto each rose plant during the first eight weeks of the trial. Similar numbers of \textit{A. swirskii} were recovered from plants with either both predator species or only predatory mites (one-way repeated measures ANOVA: $F_{1,4} = 2.17; P = 0.22$). Recovery of \textit{A. swirskii} from plants with predators started at 25.8 per cage ($\pm$ SE = 6.4; n = 6) in week 3, decreased to 12.3 per cage ($\pm$ SE = 1.6; n = 6) in week 6, and was 1.7 ($\pm$ SE = 0.7; n = 6) by week 10. Recovery of \textit{O. insidiosus} from cages with both predator species started at 4.0 per cage ($\pm$ SE = 1.2; n = 3) during week 3, peaked at 5.33 per cage ($\pm$ SE = 0.7; n = 3) during week 7, but declined until none were recovered in week 10.

![Graph](image)

Figure 1. Weekly counts of \textit{Frankliniella occidentalis} (mean + 1 SEM) from cut rose crops exposed to 'no predators' or \textit{Amblyseius swirskii} or both \textit{A. swirskii} and \textit{Orius insidiosus}. Different letter(s) above the columns indicate significant differences between predator treatments, pooled across weeks, at $P \leq 0.05$ as determined by Tukey’s HDS.

**Discussion**

In greenhouse crops, inoculative or augmentative releases of phytoseiid mites are often used as a 'first line of defence' against thrips because they are inexpensive and have a good rate of establishment in many crops. If phytoseiid mites are unable to suppress severe thrips infestations, anthocorids are often released as a corrective measure (Brodeur et al., 2002). We found that concurrent releases of both \textit{A. swirskii} and \textit{O. insidiosus} did not improve control of \textit{F. occidentalis} on cut roses. \textit{Orius insidiosus} is a generalist predator that switches to the most abundant prey and attacks beneficial species when pests are scarce (Chow et al., 2008). If \textit{O.}...
*insidiosus* readily switches from *F. occidentalis* to *A. swirskii* on cut roses, it may limit the efficacy of this combination of natural enemies. Further investigations are need to elucidate how this combination of *Orius* and *Amblyseius* species may interact in different greenhouse crops and how these intraguild interactions will affect suppression of thrips populations.

![Graph](image)

**Figure 2.** Weekly counts of *Amblyseius swirskii* (mean + 1 SEM) released from two consecutive sets of monitor sachets (set 1 = weeks 1-4; set 2 = weeks 5-8) placed among cut rose crops exposed to *Frankliniella occidentalis* with *A. swirskii* (= ) or *F. occidentalis* with both *Orius insidiosus* and *A. swirskii* ( = ), n = 3 per treatment.

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**References**


Insecticide resistance in Ontario strains of the American serpentine leafminer (*Liriomyza trifolii* (Burgess)) in Ontario

L. Conroy¹, C.D. Scott-Dupree¹, C.R. Harris¹, G. Murphy², A.B. Broadbent³
¹Department of Environmental Biology, University of Guelph, Guelph, ON Canada N1G 2W1, E-mail: lconroy@uoguelph.ca; ²Ontario Ministry of Agriculture, Food and Rural Affairs, Vineland, ON Canada L0R 2E0; ³Southern Crop Protection Food Research Centre, Agriculture and Agri-Food Canada, London, ON Canada N5V 4T3

**Abstract:** The American serpentine leafminer, *Liriomyza trifolii* (Burgess) (ASL), is a major pest of floriculture in Ontario. Growers rely heavily on chemicals to provide acceptable pest control and, as a result, ASL has developed resistance to many insecticides. Only a few are registered for use in Canada and growers have been reporting difficulty in achieving effective ASL control. The objectives of this study were to determine if ASL in Ontario has developed resistance to currently registered insecticides and to evaluate the potential of 2 newer reduced risk insecticides for inclusion in future ASL management programs.

Two ASL cultures were established – one collected from greenhouses near Vineland, Ontario, the other being an insecticide susceptible strain never exposed to any of the test insecticides. Insecticide effectiveness was assessed using a leaf dip bioassay technique. Insecticides tested were cyromazine and abamectin – both currently registered; and, 2 novel reduced risk products - spinosad and chlorantraniliprole.

At the LC₅₀, the Ontario strain was resistant (>10x) to both abamectin (17.5x) and cyromazine (10.2x). It also was significantly more tolerant to spinosad (2.8x) and chlorantraniliprole (3.0x). Comparing the LC₉₅ to application rates showed that the amount of insecticide required to kill 95% of the Ontario ASL strain would be much higher than the recommended rate for cyromazine, slightly higher for abamectin and close to the suggested application rate for spinosad. The LC₉₅ for chlorantraniliprole was much lower than the suggested application rate. Nevertheless, the low level tolerance shown by the Ontario strain suggests that this highly effective insecticide has the potential to develop a higher level of resistance and that, if registered for use, it should be in the context of a multifaceted IPM program.

**Keywords:** insecticide resistance, abamectin, cyromazine, spinosad, chlorantraniliprole, *Liriomyza trifolii*

**Introduction**

In 2006, Ontario produced about 14 million potted and 21 million cut chrysanthemums, and 3 million potted and 30 million cut gerberas (Statistics Canada, 2006). The American serpentine leafminer (*Liriomyza trifolii* (Burgess)) (ASL) attacks both crops. Floriculture producers often rely on the heavy application of chemical insecticides to control pests because consumers demand a high quality product free from aesthetic damage (Parrella, 1987; Gullino & Wardlow, 1990). Only a few insecticides are registered for ASL control in Canada (Chaput, 2000). Abamectin (Avid®) and cyromazine (Citation®, Syngenta Crop Protection Canada, are registered systemic insecticides acting on ASL larvae. Permethrin (Pounce®), FMC Corporation, can be used against ASL adults but resistance to permethrin develops rapidly (Murphy, 2004). Unfortunately, the short generation time and high reproductive rate of ASL combined with excessive insecticide use have resulted in the development of resistance to
many insecticides (Parrella, 1987). In 2004, growers in Ontario reported difficulty in controlling ASL with registered insecticides (Murphy, 2005), suggesting that it was becoming resistant. Novel reduced risk insecticides, such as spinosad and chlorantraniliprole, need to be tested for ASL control and for compatibility with IPM programs.

The objectives of this study were to determine if ASL in Ontario has developed resistance to currently registered insecticides and to evaluate the effectiveness of spinosad and chlorantraniliprole.

Materials and methods

American Serpentine Leafminer Culture
Two ASL colonies were established. A reference strain was obtained from Dr. Scott Ferguson (Syngenta Crop Protection, Florida, US). This strain had been reared in the laboratory for over 20 years and had never been exposed to currently registered insecticides. The second strain was collected from chrysanthemum and gerbera greenhouses in the Vineland region of Ontario in 2006-2007. It was accidentally imported from contaminated propagation material from the United States and may have been resistant to registered insecticides. Both strains were kept in plexi-glass cages in environmental chambers at 26 ±2ºC, 50-70% RH, and 18:6 L:D. Insects were reared on green beans (cv. Provider®, Veseys Inc.) grown in ProMix®. A 10 cm filter paper covered in dilute honey was supplied for carbohydrate.

Leaf Dip Bioassay
Bean plants (4-6) at the 2-4 leaf stage were exposed to ASL colonies for 1-3 h depending on colony fitness (# ASL per cage). Plants were removed from the colony and placed in environmental chambers (26 ±5ºC, 30-50% RH, and 18L:6D) for 2-3 d or until small mines appeared on the leaves. Mines on each leaf were counted and marked with a permanent marker. Leaves were removed and placed in flower picks filled with deionised water on a cafeteria tray lined with paper towel fitted with a metal rack. Seven to 15 mines per leaf were used per replication.

Cyromazine (Citation® 75 WP, Syngenta Crop Protection Canada), abamectin (Agri-Mek®, Avid® 1.9% EC, Syngenta Crop Protection Canada), spinosad (Success® 480 SC, Dow AgroSciences Canada) and chlorantraniliprole (Rynaxypyr™ 35% WG, DuPont Canada) were tested. Formulated insecticides were mixed with deionised water. Super Spreader® (United Agri Products Canada Inc.) wetting agent (0.05 ml) was added to each concentration. Deionised water was used as the control. One or 2 infested leaves with a total of at least 7 mines were dipped into a beaker containing 200 ml of the insecticide mixture for 5 s and were then placed on a rack in a fumehood to dry for 1 h. Leaves were then removed from the flower picks and placed in 10 cm plastic Petri® dishes lined with filter paper. Petri dishes were sealed with parafilm. Post-treatment containers were kept in an environmental chamber at 26 ±5ºC, 30-50% RH, and 18:6 L:D) for 7 d until ASL pupation. Preliminary screening tests were done to determine a range of concentrations (15-95% mortality) appropriate for construction of a dosage mortality curve. Tests were replicated 4 times.

Data Analysis
Abbott’s formula (Abbott, 1925) was used to correct for control mortality (<15%). Data were analyzed using SAS version 9.1 (SAS institute, Cary, NC) with a type 1 error rate of σ = 0.05. The probit procedure was used to determine the LC50 and LC95 values by log transforming the data to fit the probit scale. A Chi-square goodness of fit test was used to test the significance of the probit regression and determine the fiducial limits. The difference between the 2 LC50
values was deemed significant if there was no overlap of the 95% fiducial limits. Resistance levels were calculated by comparing LC$_{50}$ values.

**Results and discussion**

The Ontario ASL strain was resistant (defined as >10x) to both abamectin (17.5x) and cyromazine (10.2x), the 2 products registered for use in Canada. The Ontario strain also was significantly more tolerant to spinosad (2.8x) and chlorantraniliprole (3.0x) than the reference strain (Table 1).

Table 1. LC$_{50}$ and level of resistance of 2 American serpentine leafminer strains (O: Ontario, S: reference) exposed to formulated insecticides, either registered (abamectin, cyromazine) or novel reduced risk (spinosad, chlorantraniliprole) using a leaf dip bioassay.

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Strain</th>
<th>N</th>
<th>Slope</th>
<th>Pearson $\chi^2$</th>
<th>LC$_{50}$ (ppm)</th>
<th>95% Fiducial Limits</th>
<th>Level of Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abamectin</td>
<td>O</td>
<td>249</td>
<td>1.52</td>
<td>0.262</td>
<td>1.05</td>
<td>0.72 - 1.40</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>318</td>
<td>1.94</td>
<td>0.219</td>
<td>0.06</td>
<td>0.05 - 0.07</td>
<td></td>
</tr>
<tr>
<td>Cyromazine</td>
<td>O</td>
<td>343</td>
<td>1.40</td>
<td>0.453</td>
<td>33.6</td>
<td>26.0 - 44.0</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>220</td>
<td>3.13</td>
<td>0.087</td>
<td>3.28</td>
<td>2.24 - 4.41</td>
<td></td>
</tr>
<tr>
<td>Spinosad</td>
<td>O</td>
<td>192</td>
<td>2.14</td>
<td>0.673</td>
<td>2.82</td>
<td>2.01 - 3.67</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>177</td>
<td>2.31</td>
<td>0.121</td>
<td>1.00</td>
<td>0.81 - 1.28</td>
<td></td>
</tr>
<tr>
<td>Chlorantraniliprole</td>
<td>O</td>
<td>289</td>
<td>1.99</td>
<td>0.292</td>
<td>0.63</td>
<td>0.53 - 0.76</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>295</td>
<td>3.10</td>
<td>0.169</td>
<td>0.21</td>
<td>0.19 - 0.24</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. LC$_{95}$ for the Ontario American serpentine leafminer strain exposed to formulated insecticides through the leaf dip bioassay compared to recommended application rates.

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>LC$_{95}$ (ppm)</th>
<th>95% Fiducial Limits</th>
<th>Recommended Application Rate (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyromazine</td>
<td>506</td>
<td>301 - 1051</td>
<td>141</td>
</tr>
<tr>
<td>Abamectin</td>
<td>12.7</td>
<td>7.9 - 27.8</td>
<td>11</td>
</tr>
<tr>
<td>Spinosad</td>
<td>16.5</td>
<td>12.0 - 26.5</td>
<td>24</td>
</tr>
<tr>
<td>Chlorantraniliprole</td>
<td>4.3</td>
<td>2.6 - 11.0</td>
<td>9</td>
</tr>
</tbody>
</table>

Ferguson (2004) documented ASL resistance to cyromazine, abamectin and spinosad in Florida and anecdotal reports since 2004 have suggested that a resistant strain of ASL is present in Ontario (Murphy, 2005). These data show that the ASL present in some Ontario ornamental greenhouses is resistant to both cyromazine and abamectin (Table 1). Comparing the LC$_{95}$ to the recommended field rates (Table 2) shows that the amount of insecticide needed to kill 95% of the Ontario ASL strain is much higher than the recommended rate for cyromazine and slightly higher for abamectin. A low level of insecticide tolerance was observed with spinosad (Table 1) and the LC$_{95}$ is much closer to the application rate (Table 2). It is registered in the United States for ASL control and thus it is not surprising that the
strain in Ontario, accidentally imported from the United States would show some tolerance to this insecticide.

Chlorantraniliprole is a new insecticide with a unique mode of action. Comparing the application rate to the LC\textsubscript{95} suggests that the amount needed to provide 95% control is lower than the suggested application rate (Table 2). Nevertheless, the low level of insecticide tolerance shown by the Ontario strain to this control product suggests that it has the potential to develop resistance to it (Table 1). If chlorantraniliprole is registered for ASL control, it would be important that an IPM program be in place to minimize its use in order to delay resistance development to this novel insecticide.

These results stress the importance of developing a multifaceted IPM program for ASL control in Ontario. Insecticides alone will not control it without the rapid development of insecticide resistance. An IPM program that decreases the number of insecticide applications, rotates products with different modes of action and incorporates biological control will ensure more effective ASL control.

Acknowledgements

The authors gratefully acknowledge the participation of several greenhouse growers from the Vineland area of Ontario. We also thank Dr. Scott Ferguson (Syngenta Crop Protection, Florida US) for providing the \textit{L. trifolii} reference strain and advice; and, Kelly O’Keefe for technical assistance. Funding for this project was provided through a CORD IV Grant to Flowers Canada Ontario and a NSERC Industrial Postgraduate Scholarship 1 sponsored by Flowers Canada Ontario to L. Conroy.

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Wilt-Pruf: a novel control agent for American serpentine leafminer

L. Conroy1, A.B. Broadbent2, C.D. Scott-Dupree1, C.R. Harris1, G. Murphy3
1Department of Environmental Biology, University of Guelph, Guelph, ON Canada N1G 2W1, E-mail:iconroy@uoguelph.ca; 2Southern Crop Protection Food Research Centre, Agriculture and Agri-Food Canada, London, ON Canada N5V 4T3; 3Ontario Ministry of Agriculture, Food and Rural Affairs, Vineland, ON Canada L0R 2E0

Abstract: The appearance of insecticide-resistant American serpentine leafminer (Liriomyza trifolii (Burgess)) (ASL) in Ontario floriculture greenhouses has accelerated the search for alternative pest control methods. The objective of this study was to test efficacy of the anti-desiccant Wilt-Pruf® (WP) to deter ASL. Chrysanthemum plants sprayed with varying concentrations of WP were placed in a cage with a non-treated plant and exposed to ASL for 24 h. Residual activity of WP was evaluated over 3 and 6 d by placing treated chrysanthemums in one ASL cage and non-treated plants in another. Assessments following 24 h exposure indicated that ASL consistently chose non-treated or water treated over WP treated plants in both 3 and 6 d no-choice tests. WP may be a useful barrier to ASL in a multi-faceted IPM program.

Keywords: Liriomyza trifolii, anti-desiccants, Wilt-Pruf®, integrated pest management, deterrents

Introduction

The Ontario floriculture industry is an important part of the Canadian agricultural economy. In 2006, the floriculture industry in Ontario was worth $828 million and represented about 55% of total Canadian floriculture production (Statistics Canada 2006). The American serpentine leafminer (Liriomyza trifolii (Burgess)) (ASL), can be a devastating pest. Floriculture producers often rely on chemical insecticides to control pests because consumers demand a high quality product free from aesthetic damage (Parrella, 1987; Gullino & Wardlow, 1990). Unfortunately, the short generation time and high reproductive rate of ASL combined with excessive insecticide use have caused it to develop resistance to many insecticides (Parrella, 1987), including previously recommended insecticides in Ontario (Broadbent & Pree, 1989). Alternative control strategies are an important part of a successful IPM program, especially when a pest is known to rapidly develop resistance to conventional insecticides. Film-forming products have been studied as alternative controls for many pests (Allen et al., 1993). Wilt-Pruf® (Wilt-Pruf Products Inc.) (WP) is an anti-desiccant applied to crops to reduce the amount of water loss through transpiration. WP decreased the transmission of the Tomato spot wilt virus by the Western flower thrips by 73% (Allen et al., 1993). Preliminary studies by Legin and Broadbent (unpublished) indicated that WP might have potential to reduce ASL feeding and oviposition on chrysanthemums. The objective of this study was to determine the effectiveness of WP as a deterrent to ASL.

Materials and methods

Choice test bioassays

ASL colonies were maintained at the University of Guelph. Chrysanthemum plants (cv. White Regan) were grown in a greenhouse. Concentrated WP (25 % pinolene) was mixed with water (9:1, 6:1, 3:1; water:WP), sprayed with a hand sprayer on chrysanthemum plants and left to
dry for 2-3 h. WP treated plants were exposed to ASL along with plants that were left without treatment and plants that were sprayed with water. One plant per treatment was placed in a cage with 50 newly emerged adult ASL and a honey card, and left for 24 h (25 ±2°C, 50-70% RH, 16L:8D). Plants were removed after 24 h and placed in a growth cabinet (25 ±5°C, 30-50% RH, 16L:8D) for 5 d until small mines appeared. Mines and stipplles were counted and recorded, then plants were cut at the base and placed into labelled paper bags and stored (25 ±2°C, 50-70% RH) until ASL had pupated (ca. 1 wk). Pupae were counted and observed for adult emergence. The tests were repeated 5 times.

**No-choice test bioassays**

Methods for no-choice bioassays were similar to the choice tests. Six chrysanthemum plants were used per replication. Three were treated with water:WP (6:1), the other 3 were left without treatment. The plants were placed in 2 separate ASL cages (ca. 50 flies and 2 honey cards each) for 3 or 6 d. Mines were counted 3 d after plants were removed from the cages. Post treatment handling was similar to choice test bioassays. The bioassays were repeated 3 and 4 times respectively.

**Data Analysis**

An ANOVA was performed for both the choice and no choice tests using SAS 9.1. Means were compared using Tukey’s adjusted Least Significant Means comparison with α=0.05.

**Results and discussion**

**Choice test bioassays**

ASL consistently chose non-treated and water treated plants over WP treated plants (Figure 1). No significant differences in mean number of mines were observed between non-treated and water treated chrysanthemums. No differences in mean number of mines were observed among WP treatments. Pupal and adult emergence was not analyzed due to high variability. Mines frequently did not develop pupae.

**No-choice test bioassays**

Treated chrysanthemum plants had significantly less mines compared to non-treated plants in both 3 and 6 d no-choice tests (Figure 2). More mines were observed in 3 d trials due to higher numbers of ASL adults. ASL introduction was refined for the 6 d trials resulting in a more consistent number of mines among replications. These results indicate that WP can slow ASL oviposition for at least 1 wk, decreasing the amount of insecticidal control. WP has potential as a deterrent in multi-faceted IPM programs however; the economics and application of this novel approach must first be evaluated.

**Acknowledgements**

The authors gratefully acknowledge the participation of several greenhouse growers from the Vineland area of Ontario. We also thank Justin Glatt for technical assistance. Funding for this project was provided through an Agriculture Adaptation Council CORD IV Grant to Flowers Canada Ontario and a NSERC Industrial Postgraduate Scholarship 1 sponsored by Flowers Canada Ontario to L. Conroy.
Figure 1. Choice tests to determine Wilt-Pruf® efficacy (at 9:1, 6:1, 3:1 water:Wilt-Pruf ratios) as a deterrent to American serpentine leafminer (*Liriomyza trifolii*) on chrysanthemums (cv. White Reagan). Bars with the same letter are not significantly different. N=25, α=0.05.

Figure 2. No-choice tests (3 and 6 days) to determine Wilt-Pruf® efficacy as a deterrent to American serpentine leafminer (*Liriomyza trifolii*) on chrysanthemums (cv. White Reagan). Plants were treated with water:Wilt-Pruf (6:1). N=42. α=0.05.
References


Artificial production of arthropod biological control agents

Patrick De Clercq
Laboratory of Agrozoology, Department of Crop Protection, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium, E-mail: patrick.declercq@ugent.be

Abstract: Augmentative biological control should be based on a cost effective and reliable production of high-quality natural enemies (Bolckmans, 2007). To reduce costs, alternatives have been proposed for a number of tritrophic rearing systems (i.e., those including the plant, natural prey or host, and predator or parasitoid levels) and some of these have found their way into practice. Currently, several species of mites and insects are being used as factitious prey or hosts for the complete or partial commercial production of arthropod predators and parasitoids, including bran mites and dried fruit mites for phytoseiids, lepidopteran eggs for heteropteran, coleopteran and chrysopid predators and for trichogrammatid parasitoids, and brine shrimp cysts for heteropteran predators (De Clercq, 2004). Artificial diets (or media) have been developed, with a varying degree of success, for various beneficial arthropods, but the practical use of these diets is still in its infancy (Grenier & De Clercq, 2003, 2005). Only very few of these artificial diets are nowadays routinely used in commercial insect cultures (e.g., the diet developed by Cohen (2003) for Chrysoperla spp.). It deserves emphasis that the development of artificial foods for beneficial arthropods is not about nutrition alone. The complexity of designing artificial media requires inputs from nutritionists, food technologists and process engineers, microbiologists, insect ecologists, physiologists and geneticists (see the potential of genomics and other –omics as tools in diet development). A major concern is the quality of artificially reared natural enemies (Grenier & De Clercq, 2003, 2005). Assessing development and particularly reproduction of natural enemies reared on an unnatural food is often a time consuming activity. In this respect, increasing attention is given to the development of rapid tools to assess reproductive potential, including dissection tests (e.g., Vandekerkhove et al., 2006) and ELISA-based detection of yolk proteins (e.g., Shapiro et al., 2000). Arguably, excellent field performance of the artificially produced natural enemy against the target pest remains the ultimate quality criterion. However, quality assessments of artificially reared natural enemies have mostly been performed at a laboratory scale or in semi-field conditions, and only rarely so in practical field conditions (Grenier & De Clercq, 2005). Besides animal foods, many natural enemies require plant materials for moisture, supplementary nutrients or growth factors, or as an oviposition substrate. Replacement of plant substrates for oviposition by artificial substrates constitutes a further challenge for the rationalisation of rearing processes for several predatory insects that deposit their eggs in plants tissues, like mirid and anthocorid bugs.

Key words: factitious foods, artificial diets, rearing, quality assurance, augmentation biological control

References


Combined use of predatory mites for biological control of *Tetranychus urticae* (Acari: Tetranychidae) in commercial greenhouse cucumber

Gillian Ferguson
Ontario Ministry of Agriculture, Food and Rural Affairs, 2585 County Rd 20, Greenhouse and Processing Crops Research Centre, Harrow, ON, N0P 2G0, Canada, E-mail: gillian.ferguson@ontario.ca.

Abstract: Two types of predators were used for biological control of spider mites (*Tetranychus urticae*) in commercial greenhouse cucumber crops. Initial general releases of *Neoseiulus californicus* were followed by targeted releases of *Phytoseiulus persimilis* in areas with higher populations of *T. urticae*. This strategy combined the biological traits of the less specialized *N. californicus* with those of the highly specialised *P. persimilis* to successfully suppress *T. urticae* populations under commercial conditions.

Key words: *Tetranychus urticae*, *Neoseiulus californicus*, *Phytoseiulus persimilis*, greenhouse cucumber

Introduction

Biological control of *Tetranychus urticae* in greenhouse cucumbers has been very challenging for commercial growers in south-western Ontario, Canada. Traditionally, biological control programs for *T. urticae* relied principally on *Phytoseiulus persimilis*. Often however, programs would fail particularly during the summer months when low humidity and high temperature conditions favoured *T. urticae*, but not *P. persimilis*. In efforts to improve biological control of *T. urticae*, the strategy of combining the less specialised *Neoseiulus californicus*, together with the diet-specialist, *P. persimilis*, was adopted in trials with commercial growers. The ability of *N. californicus* to perform efficiently under a range of temperature conditions (Rott & Ponsonby, 1998) and to survive for relatively long periods without food or water (de Courcy Williams & Kraver-Garde, 2002) made it a good candidate for partnering with *P. persimilis*. *P. persimilis* is known to have a high prey consumption rate, and exhibits a rapid numerical response to increasing *T. urticae* populations (McMurtry & Croft, 1997). In addition, work by several researchers (Blümel et al., 2002; Menyhert & Linden, 2002; Walzer & Schausberger, 2002) indicated that this approach held much promise for biological control of *T. urticae* in a commercial situation.

Material and methods

**Trial 1**

This trial took place in a section of a commercial crop that was planted in the greenhouse on November 28, 2002. The area of the section dedicated to biological control of spider mites was 6,271 m². Monitoring of cucumber plants began during the first week of December 2002, and continued weekly until the end of February. Release of predators began at first sign of *T. urticae* which occurred in early December, shortly after monitoring began. Releases started on December 7 and consisted of a total of five fortnightly releases of the coccinellid, *Stethorus punctillum* at a rate of about 1.2/m² on each release date. On December 18, *N. californicus*
was released at a rate of 9/m² in just two locations where very early damage symptoms of *T. urticae* were detected. Five days after this initial limited release of *N. californicus*, additional early signs of *T. urticae* damage in other locations warranted a “blanket” or general application of *N. californicus* using a rate of about 4/m² throughout the entire crop. No further releases of this predator were made. Releases of *P. persimilis* did not begin until mid-January when ex-diapausing *T. urticae* began to emerge from the structure in the initial two spots in the greenhouse. Between January 14 and February 5, a total of about 130 *P. persimilis*/m² were released in these two locations on dates indicated in Figure 2. Observations were carried out with a 12X hand lens magnifier and were concentrated in the two highly infested areas or “hot spots”. In each of these areas, approximately 16 leaves were examined weekly. Only leaves with symptoms of feeding damage were selected for examination. Although the majority (77%) of leaves examined were from the upper canopy, those from the mid- and lower canopies were also examined. Data collected per leaf included visual assessments of 1) percentage live *T. urticae*, 2) number of live *N. californicus*, 3) number of live *P. persimilis*, and 4) damage - using an arbitrary rating scheme as follows: 0 = No damage; 1 = incipient damage - <1.4 cm in diameter; 2 = total of damaged area 1.5-5.0 cm in diameter; 3 = total of damaged area 5.1-7.5 cm in diameter; 4 = total of damaged area 7.6-10 cm in diameter; 5 = total of damaged area >10 cm inches in diameter.

**Trial 2**

During the spring of 2006, both *N. californicus* and *P. persimilis* were used in a 1.6-ha commercial cucumber operation for management of *T. urticae*. As in Trial 1, release of predators began at first sign of *T. urticae* feeding symptoms, which occurred when the crop was four weeks old in early April. Release rates for the predatory mites were determined by the grower. The first releases consisted of two blanket releases of *N. californicus* at a rate of approximately 4.5/m² for two consecutive weeks at one week apart. This was followed by blanket releases of *P. persimilis* at a rate of about 4.5/m² for three consecutive weeks because of increasing *T. urticae* feeding damage. More predators were applied to the hot spots. Observations were carried out until late June in three hot spot areas that measured between 210 to 280 m². Data collected were similar to those described for Trial 1.

**Results and discussion**

**Trial 1**

Initial damage in the hot spots was initially minimal, but developed to a level where the average damage rating for one location was 2.3, and that for the other was 3.4. Figure 1 provides data for the percentage live *T. urticae* observed on leaves examined between 7 January and February 25, 2003. Figure 1 shows that the percentage of live *T. urticae* in both locations dropped significantly from high levels (80-84%) in early January to very low levels (3-18%) by the end of January. By the end of February, the percentage of live *T. urticae* had decreased to <1-3%. At that time, a flush of healthy new growth indicated complete suppression of *T. urticae* populations using only predatory mites. Indeed, no further outbreaks occurred for the remainder of the crop, which ended a month later.

The percentage of leaves on which predators were observed was similar for both hot spots, therefore the combined data are presented in Figure 2. The early inoculative release of *N. californicus* was sufficient to provide a reasonable presence of this predator throughout the period of observation. Figure 2 shows that at the end of February, two months after the blanket release was made, *N. californicus* could be seen on about 45% of all leaves examined. *P. persimilis* was present on a higher percentage (80%) of leaves, but many more releases
were made to ensure that they were present in sufficient numbers to achieve adequate suppression of *T. urticae* populations. For the duration of this trial, the number of predators observed per leaf varied from one to seven for *N. californicus*, and from one to 10 for *P. persimilis*. No *S. punctillum* was observed for the entire period. It may be that the number of *S. punctillum* released might have been inadequate, or that conditions were unsuitable for this predator at that time of year.

Figure 1. Average percentage live spider mites (*T. urticae*) per leaf in two locations of high infestation in a commercial greenhouse cucumber crop.

Figure 2. Average percentage of leaves with either *N. californicus* or *P. persimilis* in a commercial greenhouse cucumber crop. Arrows indicate dates of predator releases; unmarked arrows are those for *P. persimilis*. 
**Trial 2**

The gradual general releases of both predatory mites did not retard the development of the hot spots in this trial. However, the abundance of spider mites developing in these same hot spots facilitated proliferation of *N. californicus* and *P. persimilis*. It is likely that the high temperature conditions at that time of year favoured rapid population build-up of *T. urticae* versus the predators. The damage inflicted in the hot spots increased each week and had attained a level that warranted chemical intervention. An application of bifenazate was considered necessary after the third release of *P. persimilis*. At that time, the average damage rating was 4.3, and about 30% of the leaves were totally chlorotic. The bifenazate intervention resulted in a dramatic reduction of live *T. urticae*. Within 24 hr, mortality was on average, at least 95%. Observations of the hot spots at eight days following the bifenazate application revealed average numbers of up to eight *P. persimilis* per leaf, with some leaves having as many as 40 on one leaf. Numbers of *A. californicus* were on average lower, with slightly more than one per leaf, and as many as five on one leaf. Populations of *P. persimilis* were relatively high for up to two weeks following the bifenazate application. Thereafter, they were not observed, likely due to starvation. *N. californicus*, on the other hand, persisted for at least six weeks after the bifenazate application. The net result of several predator releases and one miticide intervention was complete suppression of spider mite populations in the hot spots, substantiated by an abundance of new axillary shoots free of *T. urticae*. Possibly, the one chemical application may have been avoided if initial releases of the predators were more aggressively carried out by using higher release rates to achieve suppression in a shorter period of time.

**Acknowledgements**

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Comparative efficacy of oil- versus aqueous-based formulations of the entomopathogenic fungus *Beauveria bassiana* applied against melon aphid, *Aphis gossypii*

Melanie Filotas¹, John Sanderson¹, Stephen Wraight²

¹Department of Entomology, Cornell University, Ithaca, NY, USA, 14853, E-mail: jps3@cornell.edu; ²USDA-ARS, Robert W. Holley Center for Agriculture and Health, Ithaca, NY, USA, 14853

Abstract: Oils are known to act as highly effective spray stickers and have been claimed to improve efficacy of fungal pathogens under dry conditions. Oil formulation is thus considered one of the most promising technologies for improving efficacy of mycoinsecticide spray applications. The objective of this study was to investigate effects of oil vs. water formulation on the efficacy of *Beauveria bassiana* conidia applied against *Aphis gossypii* under relatively dry conditions. In laboratory tests, formulation in emulsifiable oil did not significantly increase virulence of the fungus nor increase its capacity to infect aphids under dry conditions compared to unformulated fungus. Nevertheless, the oil formulation was consistently more effective than a wettable powder. The results support a hypothesis that oils function primarily as spray stickers, improving the efficiency of spray applications.

Key words: *Beauveria bassiana*, *Aphis gossypii*, mycopesticide, oil formulation, aqueous formulation

Introduction

More than 170 mycopesticide formulations have been developed for commercial use over the past four decades (Faria & Wraight, 2007). Products based on the hydrophobic aerial conidia of such common entomopathogenic fungi as *Beauveria bassiana* and *Metarhizium anisopliae* are most commonly formulated as wettable powders (WP) or emulsifiable oil dispersions (OD). Numerous laboratory studies have indicated superior efficacy of OD versus WP formulations against a broad range of insect pests (see Wraight et al., 2001); however this greater laboratory efficacy of OD formulations has not consistently translated into improved pest control (Olson & Oetting, 1999; Wraight & Ramos, 2002; Maranga et al., 2005).

Numerous mechanisms have been claimed or proposed to account for the potential of oil formulants to enhance the activity of fungal pathogens, including: 1) action as spray stickers with strong affinities for the waxy surfaces of fungal conidia and the cuticles of both insects and plant foliage; 2) action as spreaders that improve distribution of conidia on targeted surfaces, potentially depositing fungal conidia into micro-niches on the insect body (e.g., intersegmental folds) where conditions are favourable for germination and infection; 3) formation of protective films that reduce impacts of environmental stresses such as UV radiation and desiccation, and 4) dissolution of the protective layers of insect epicuticular waxes, enhancing speed and success of penetration (infection).

Aphids have proven difficult to control with mycoinsecticide products. Being members of the order Hemiptera (suborder Sternorrhyncha), these insects have piercing-sucking mouthparts and thus do not acquire fungal inoculum from contaminated foliage during feeding, as do insects with chewing mouthparts. Many aphids also prefer to feed on new foliage in the tops of plants, where they may be exposed to ambient environmental conditions
that are unfavourable for fungal infection. Aphids also have exceptionally smooth, waxy cuticles, characteristics that tend to promote dry conditions on the cuticle surface. As a consequence of these attributes, successful aphid control with microbial control agents will depend upon development of efficient formulation and delivery systems. Considering the above-described mechanisms associated with oils, oil formulation is one of the most promising technologies for enhancing efficacy of fungal pathogens against aphids and other hemipteran pests. This report presents initial results from laboratory studies aimed at assessing the potential of oil formulation to enhance efficacy of mycoinsecticide sprays against aphid pests of greenhouse ornamentals.

Materials and methods

Insect rearing
Melon aphids (Aphis gossypii) were maintained on potted cucumber plants (Cucumis sativus cv. Marketmore 76) at 25 ±2°C with a 14 h daily photoperiod. To produce even-aged cohorts of aphids for use in bioassays, adult aphids were placed on excised cucumber leaves for 24 h. First-instar nymphs from these plants were then transferred to whole plants and reared to the adult stage. Adult apterae (7-9 d old) were ultimately selected for use in bioassays.

Fungal inocula preparation
Conidia of B. bassiana strain GHA were produced by Laverlam International Corporation (Butte, MT; formerly Emerald BioAgriculture) using proprietary methods. Materials obtained included an unformulated technical powder (TP), a clay-based wettable powder (WP) (BotaniGard 22 WP), and a paraffinic oil-based emulsifiable dispersion (OD) (BotaniGard ES). Three different batches of WP and OD and two batches of TP were used, assigned randomly among the assays. Inocula for multi-dose bioassays were prepared by mixing the TP, WP, and OD at high rates of 3.75 mg, 13.5 mg, and 15 µl per ml deionized water. The unformulated TP was suspended using a low concentration of wetting agent (0.01% Silwet). Four lower concentrations of each formulation were then prepared by making four 5-fold dilutions of the high concentration.

Bioassay protocol
Bioassay chambers comprised 60-mm diameter Petri dishes with 45-mm diameter cucumber leaf disks embedded, adaxial surface down, in 3% water agar. Five dishes, each with 5–6 adult aphids were sprayed with each rate of each formulation (125-150 aphids/formulation/assay) using a spray tower that deposited approximately 0.013 µl suspension/mm² of abaxial leaf surface. Control dishes were sprayed with formulation blanks at rates equivalent to the high dose and then covered with ventilated (screened) lids and incubated 24 h at 25 ±1°C with 14 h daily photoperiod. Relative humidity measured inside the assay chambers was 75 ±3%. At 24 h post-treatment, all aphids were transferred to dishes with fresh, untreated leaf disks. An additional change of leaf disks was made at 96 h post-treatment. Aphid mortality was recorded 7 days post-treatment. Conidial depositions were sampled directly on plastic cover slips placed in the spray tower during all spray applications, and spore concentrations were determined by direct counts. Samples of all spray suspensions were also collected on Petri dishes containing water agar with 0.5% yeast extract for determinations of conidial viability (>90% in all cases). A total of 15 bioassays were conducted (3 formulations tested on each of 8 dates in a randomised complete block design).

Results and discussion
Results from probit analysis of the bioassay data are presented in Table 1. Mortality among
aphids treated with the carrier blanks averaged <10% in all cases. The low doses across assays (in which conidia and carrier ingredients were diluted to very low levels) produced mortality equivalent to the carrier controls, indicating the carriers were nontoxic at the applied rates. The fungus was not highly pathogenic toward the aphids under the conditions of this test, with LC$_{50}$'s exceeding 2300 conidia/mm$^2$. Results were unexpected in that oil formulation failed to significantly increase the efficacy of \textit{B. bassiana} relative to the unformulated TP. Generally, it appeared that oil formulation slightly increased efficacy and WP formulation slightly decreased efficacy, such that the only significant difference was between the OD and WP (F$_{2,8}$=5.6, P=0.031 and see Table 1). No significant differences were noted between the probit regression slopes of the three formulations (F$_{2,8}$=1.0, P=0.41).

Table 1. Median lethal concentrations (LC$_{50}$) and probit-regression slopes from replicated bioassays of formulated and unformulated \textit{B. bassiana} against adult melon aphids.

<table>
<thead>
<tr>
<th>Treatment$^a$ (number of assays)</th>
<th>Slope</th>
<th>LC$_{50}$$^b$</th>
<th>Percent carrier control mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical powder (5)</td>
<td>1.45 ± 0.05 a</td>
<td>4160 ± 594 ab</td>
<td>8.2 ± 0.9 a</td>
</tr>
<tr>
<td>Wettable powder (5)</td>
<td>1.38 ± 0.14 a</td>
<td>6074 ± 1056 b</td>
<td>8.4 ± 1.8 a</td>
</tr>
<tr>
<td>Oil dispersion (5)</td>
<td>1.20 ± 0.12 a</td>
<td>2326 ± 738 a</td>
<td>10.7 ± 1.3 a</td>
</tr>
</tbody>
</table>

$^a$Means (± standard error) within columns followed by same letter are not significantly different (Tukey's HSD, alpha = 0.05). $^b$Prior to probit analysis, data were adjusted for carrier-control mortality using Abbott's correction.

Table 2. Percent mortality of adult melon aphids treated with \textit{B. bassiana} conidia formulated as a wettable powder, emulsifiable oil dispersion, or unformulated technical powder.

<table>
<thead>
<tr>
<th>Treatment$^a$ (number of assays)</th>
<th>Viable conidia/mm$^2$</th>
<th>Total percent mortality (uncorrected)</th>
<th>Carrier control mortality</th>
<th>Corrected mortality$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low concentration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical powder (5)</td>
<td>125 ± 30 a</td>
<td>23.3 ± 6.9</td>
<td>8.2 ± 0.9 a</td>
<td>18.4 ± 7.1</td>
</tr>
<tr>
<td>Wettable powder (5)</td>
<td>133 ± 25 a</td>
<td>15.1 ± 3.2</td>
<td>8.7 ± 0.9 a</td>
<td>8.4 ± 3.9</td>
</tr>
<tr>
<td>Oil dispersion (5)</td>
<td>137 ± 17 a</td>
<td>26.9 ± 5.7</td>
<td>10.2 ± 1.4 a</td>
<td>19.3 ± 5.0</td>
</tr>
<tr>
<td>High concentration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical powder (5)</td>
<td>2050 ± 417 a</td>
<td>46.8 ± 4.4</td>
<td>8.2 ± 1.5 a</td>
<td>42.0 ± 5.1</td>
</tr>
<tr>
<td>Wettable powder (5)</td>
<td>1987 ± 380 a</td>
<td>29.0 ± 6.2</td>
<td>8.2 ± 3.3 a</td>
<td>23.8 ± 7.5</td>
</tr>
<tr>
<td>Oil dispersion (5)</td>
<td>2106 ± 439 a</td>
<td>58.2 ± 2.5</td>
<td>11.1 ± 2.6 a</td>
<td>52.9 ± 2.8</td>
</tr>
<tr>
<td>Means</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical powder (5)</td>
<td>–</td>
<td>35.1 ± 5.5 ab</td>
<td>–</td>
<td>30.2 ± 5.6 ab</td>
</tr>
<tr>
<td>Wettable powder (5)</td>
<td>–</td>
<td>22.1 ± 4.4 b</td>
<td>–</td>
<td>16.1 ± 5.0 b</td>
</tr>
<tr>
<td>Oil dispersion (5)</td>
<td>–</td>
<td>42.6 ± 6.1 a</td>
<td>–</td>
<td>36.1 ± 6.5 a</td>
</tr>
</tbody>
</table>

$^a$Means (± standard error) within columns and treatment groups followed by same letter are not significantly different (Tukey’s HSD, alpha = 0.05). $^b$Data from each assay were adjusted for carrier-control mortality using Abbott’s correction.

In 4 of 15 assays, mortality was low (≤ 30%), and LC$_{50}$’s could be estimated only by extrapolation. Because of this problem, percent mortality data from a selected low and high
dose were further analysed by ANOVA. Results were similar to those from the probit analyses, with significant differences among both the uncorrected and corrected mean mortalities being noted only between the WP and TP formulations ($F_{2,20}=6.7$ and $6.2$, $P=0.006$ and $P=0.008$, respectively and see Table 2). There were no significant formulation × dose interactions. Additional factorial ANOVAs of the uncorrected data indicated no fungus × WP carrier or fungus × OD carrier interactions ($F_{1,28}=2.5$ and $0.17$, $P=0.12$ and $0.69$, respectively).

The small effect of oil formulation on fungal efficacy was unexpected and contrasts with numerous studies that have demonstrated substantial enhancement of efficacy by oil formulation. If the sticking properties of oil are the predominant characteristic responsible for this enhanced activity, the minimal improvement observed in the present study may be related to the very low volume of our spray applications (translating to 130 l/ha). This value is far below the label-recommended spray volumes for the BotaniGard products. The sticking action of emulsified oil droplets would be expected to enhance deposition on the target under runoff conditions, as flowing oil droplets would be strongly attracted to the waxy surfaces of insect or plant cuticle. The mechanism underlying the apparent reduction in efficacy due to WP formulation is unknown. Spray droplets are known to bounce off hydrophobic surfaces, and oils have been shown to reduce spray bounce. Also, strong surfactants (as used in WP formulations) are known to cause coalescence and drainoff of spray droplets.

The equivalent probit regression slopes and small differences in efficacy of the OD vs. TP formulations combined with the incapacity to substantially improve fungal activity under low-humidity conditions support a hypothesis that oil formulants act primarily as spray stickers and spreaders that enhance dose retention on targeted surfaces.

Acknowledgements

We thank Emerald BioAgriculture and Laverlam International for providing the fungal formulations and formulation blanks. This research was funded in part through a Specific Cooperative Agreement between the USDA/ARS and Cornell University (SCA #58-1907-4-447) as part of the Floriculture and Nursery Research Initiative. This paper reports the results of research only. Mention of a product does not constitute a recommendation or endorsement for its use by the US Department of Agriculture.

References


The effect of reduced risk pesticides for use in greenhouse vegetable production on bumble bees (*Bombus impatiens* Cresson)

A.E. Gradish¹, C.D. Scott Dupree¹, L. Shipp², C.R. Harris¹, G. Ferguson³

¹Department of Environmental Biology, University of Guelph, Guelph, ON, Canada, N1G 2W1, E-mail: agradish@uoguelph.ca; ²Agriculture and Agri-Food Canada, Greenhouse and Processing Crops Research Centre, Harrow, ON, Canada, N0R 1G0; ³Ontario Ministry of Agriculture, Food and Rural Affairs, Harrow, ON, Canada, N0R 1G0

Abstract: In recent years, bumble bees (*Bombus impatiens* Cresson) have increasingly been used commercially for pollination in greenhouses and now play an essential role in Canadian greenhouse vegetable production. Effective pest control also is crucial to producing high, marketable yields of greenhouse vegetables and pesticides remain an important tactic in greenhouse integrated pest management (IPM) programs. Many pesticides are toxic to other bee species, yet pesticide toxicity data on bumble bees are lacking. We examined the toxicity of reduced risk pesticides for use in greenhouse vegetable production to bumble bees. The active ingredients (technical grade > 95% purity) of fungicides (fludioxonil, cyprodinil, myclobutanil) and insecticides (imidacloprid, metaflumizone, abamectin, chlorantraniliprole) were applied to adult bumble bee workers using a Potter spray tower (PST) to determine their relative toxicities. All of the fungicides were harmless. Imidacloprid, abamectin, and metaflumizone were harmful, while chlorantraniliprole was harmless.

Key words: bumble bees, *Bombus impatiens*, pesticides, non-target, toxicity, greenhouse

Introduction

Bumble bees are important indigenous pollinators in Canada. In recent years, they have increasingly been used for pollination in commercial greenhouses and they now play an essential role in greenhouse vegetable production (Morandin *et al.*, 2001). Effective integrated pest management (IPM) also is crucial to producing high, marketable yields of greenhouse vegetables. Pesticides remain an important management tool in greenhouse IPM programs. Fungicides are routinely applied for powdery mildew (PM) management and control of insect pests occasionally requires insecticide application. These pesticides potentially can have non-target toxic effects, especially on bumble bee pollinators.

Bumble bees are at risk of pesticide exposure in greenhouses during foraging through direct contact with foliar sprays or by consuming contaminated pollen. The most obvious effect is the acute mortality of workers following exposure. However, pesticides also may have significant chronic sub-lethal effects on bumble bees including behavioural changes, reduction in pollen gathering, reduced fecundity, abnormal development, and shortened lifespan (Tasei *et al.*, 2000). Therefore, in order for greenhouse pollination programs to be successful, accurate information on the toxicity of pesticides to bumble bees must be available. Most studies investigating pesticide impact on bees have focused on honey bees. However, there are important differences between bumble bees and honey bees that likely result in variation in their susceptibility to pesticides (Thompson & Hunt, 1999). It is essential to generate more toxicity data on bumble bees to accurately determine the potential non-target effects of pesticide application on greenhouse pollination programs. Currently, there are no published studies investigating the effect of fungicides on bumble bees. The available data...
suggest that insecticides can have direct and sub-lethal effects on bumble bees (Incerti et al., 2003). Our objective was to determine the direct contact toxicity of reduced risk pesticides for use in greenhouse vegetable production to bumble bee adults.

Materials and methods

Pesticides

All pesticides tested were technical grade (> 95% purity) and included the fungicides myclobutanil (Dow Agrosciences Canada), cyprodinil, and fludioxonil (Syngenta Crop Protection Canada), and the insecticides imidacloprid (Bayer CropScience Canada), metaflumizone (BASF Canada), abamectin (Syngenta Crop Protection Canada), and chlorantraniliprole (DuPont Canada). Myclobutanil, cyprodinil, and fludioxonil are currently registered for greenhouse PM control. Imidacloprid and abamectin are registered for greenhouse whitefly [Trialeurodes vaporariorum (Westwood)] and spider mite (Tetranychus urticae Koch) control respectively. Metaflumizone and chlorantraniliprole are novel reduced risk products currently not registered for use in Canada. Metaflumizone will be used for cucumber beetle [Acalymma vittatum (Fabricius)] and lygus bug [Lygus hesperus (Knight)] and chlorantraniliprole will be used for cabbage looper (Trichoplusia ni Hubner) and other Lepidopteran pests.

Direct contact toxicity bioassay

Direct contact toxicity bioassays were conducted at the Southern Crop Protection and Food Research Centre - Agriculture and Agri-Food Canada in London, ON using a Potter spray tower (PST) (Potter, 1952). Pesticides were dissolved in a 19:1 acetone:olive oil solution. Adult worker bumble bees were anaesthetized with CO2 and placed dorsal side up in a glass 10 cm Petri dish bottom containing a piece of 9 cm filter paper. The dish was placed in the PST and 5 ml of the corresponding treatment was applied. Controls were treated with a 19:1 acetone and olive oil solution. Each fungicide and metaflumizone was tested at four concentrations: 0.001, 0.01, 0.1, and 1% solution w/v. Imidacloprid, abamectin, and chlorantraniliprole were tested at 0.0001, 0.001, 0.01, and 0.01% solution. Four replicates, each containing 9-11 bumble bees, were treated at each concentration. Post-treatment containers were maintained in the dark at 25±1°C and 35% RH. Mortality was assessed at 48 h and 72 h for the fungicides and insecticides, respectively. Insecticide-treated bees were checked at 72 h as some products (metaflumizone and imidacloprid) are slower acting. Control mortality did not exceed 10% and natural mortality was corrected for using Abbott’s formula (Abbott, 1925). Pesticides were ranked harmless (< 25%), slightly harmful (25-50%), moderately harmful (51-75%), or harmful (> 75%) according to standards of the International Organization of Biological Control (IOBC) (Sterk et al., 1999).

Results and discussion

All of the fungicides caused no to minimal mortality at all concentrations (Table 1). Imidacloprid, metaflumizone, and abamectin were harmful at 0.01 and 0.1% solution (Figure 1). Chlorantraniliprole was harmless at all concentrations (Figure 1). All fungicides tested were harmless to bumble bees and appear safe to apply for PM management in their presence. Imidacloprid, metaflumizone, and abamectin were harmful; however, chlorantraniliprole could potentially be a safer alternative for greenhouse insect pest IPM programs.
Table 1. Direct contact toxicity of three technical grade fungicides (fludioxonil, cyprodinil, and myclobutanil) to bumble bee (*Bombus impatiens*) workers 48 h after exposure using a Potter spray tower.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average corrected % mortality of bumble bees at fungicide solution indicated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
</tr>
<tr>
<td>fludioxonil</td>
<td>202</td>
</tr>
<tr>
<td>Cyprodinil</td>
<td>202</td>
</tr>
<tr>
<td>myclobutanil</td>
<td>195</td>
</tr>
</tbody>
</table>

Figure 1. Direct contact toxicity of four reduced risk insecticides [imidacloprid (n=207), metaflumizone (n=202), abamectin (n=199), and chlorantraniliprole (n=197)] to bumble bee (*Bombus impatiens*) workers 72 h after exposure using a Potter spray tower (R²=0.9092, SE=0.01413). Data were arcsine square root transformed prior to analysis; back transformed means are shown. Columns with the same letter are not significantly different (Tukey’s, α=0.05).

Bumble bee colonies are placed in greenhouses for up to 8 weeks. Successful pollination depends in part on the bees’ ability to produce large numbers of offspring to forage during that time. When pesticides are applied, bumble bees may collect contaminated pollen repeatedly for adult and brood consumption. Even if they show no toxicity when directly applied, all the pesticides tested may cause chronic sub-lethal effects in bumble bees following long term oral exposure through contaminated pollen. Therefore, further investigation is needed to assess the impact of these formulated pesticides at label rates on bumble bee life span and brood production.
Acknowledgements

Funding for this project was provided by an Agricultural Adaptation Council CORD IV grant received from the Ontario Greenhouse Vegetable Growers Association and a grant from the Minor Use Research Initiative, Pest Management Centre, Agriculture and Agri-Food Canada (AAFC). We also thank Dale McArthur and Dr. Ian Scott from AAFC and Shannon Daradick for guidance and assistance conducting the bioassays.

References


Complex interactions between *Rhizoglyphus robini* and *Fusarium oxysporum*: implications on onion pest management

Tal Hanuny¹, Moshe Inbar¹, Leah Tsror², Eric Palevsky³

¹Department of Evolutionary and Environmental Biology, University of Haifa, Mount Carmel, Haifa 31905, Israel, E-mail: thanuny@study.haifa.ac.il, minbar@research.haifa.ac.il; ²Department of Plant Diseases, Institute of Plant Protection, Agricultural Research Organization (ARO), Gilat Research Center, D.N. Negev, 85280, Israel, E-mail: tsror@volcani.agri.gov.il; ³Department of Entomology, Institute of Plant Protection, ARO, Newe-Ya’ar Research Center, Ramat Yishay, 30095, Israel, E-mail: palevsky@volcani.agri.gov.il

Abstract: The effects of the soilborne pathogen *Fusarium oxysporum* and the bulb mite *Rhizoglyphus robini* on onion sprout survival were experimentally tested in pots and an in-vitro bioassay (Petri dishes). Survival after 8 weeks in potted plants although significant, was subtle. However in the in-vitro bioassay, within 4 days we detected severe additive effects of the pathogen and mite on onion sprout rootlet growth. The importance of host-plant, fungi and mite interactions with respect to control are discussed.

Key words: *Rhizoglyphus robini*, *Fusarium oxysporum*, weakly-pathogenic fungi, onion, control

Introduction

The bulb mite *Rhizoglyphus robini* Claparède is known as a pest of Liliaceae and is associated with fungi (Diaz et al., 2000). Recently we reported on the effects of various fungi on onion seedling survival, subsequently focusing on the interaction between a weakly pathogenic fungus (then identified morphologically as a purple strain of *Fusarium moniliforme*) and the bulb mite with respect to attraction and plant growth (Hanuny et al., 2007). In this proceeding report we present additional information on the interaction between this fungus and the bulb mite at two spatial and temporal scales. On potted plants over eight weeks we evaluated onion seedling survival and in a Petri dish on onion sprouts we assessed the effects of the fungus and the mite on rootlet growth and the effect of the fungus on mite fecundity.

Materials and methods

Mite and the fungus

A fungus, isolated from onion in the Hula Valley, Israel in 2005, originally identified morphologically as a purple strain of *F. moniliforme* (Hanuny et al., 2007), was molecularly identified as *F. oxysporum* using the translation elongation factor EF-1α, nuclear ribosomal internal transcribed spacer (ITS), β-tubulin and H3 histone genes (courtesy of M. Maymon and S. Freeman, Volcani Center, Israel). *R. robini* collected on lily from the Sharon region, Israel have since been reared in the lab in darkness on peanuts in Petri dishes (Gerson et al., 1991). Unless stated otherwise all rearing and experiments were conducted at at 25 ±1°C. When mites were contained in Petri dishes or wells the bottom of the Petri
dish/well were lined with white wet filter paper and the upper rims were ringed with vaseline to prevent escape.

The effect of the mite and the fungus on the survival of potted seedlings

The experimental unit was a 360-cc pot sown shallowly with 12 seeds of onion CV ‘Ada 781’ in a sterilized soil mix (“Shaham”, Givat Ada, Israel). Each pot was treated with one of the following four treatments (8 replicates): 1) four ml of conidial suspension of *F. oxysporum* (4x10^5 conidia/pot), 2) 100 fecund females mites, individually places with a fine paint brush, 3) treatments 1+2 combined, 4) four ml of sterilized water serving as the negative control. The potted plants were randomly placed in an incubator with four shelves, two complete replicates (blocks) per shelf. Experimental conditions were typical to the fall (*R. robind* infestations are often observed during this period): L:D 11:13, 28 ±3°C, 17 ±3°C, respectively, and RH 75 ±15%. Pots were watered with 100 ml of distilled water every 3 days. Seedling survival was recorded once a week for 8 weeks. A two way ANOVA and pair-wise comparisons according to Tukey (P<0.05) were performed with the statistical program JMP (version 5.0.1, SAS institute, 2002), taking into account the block effect of the shelves.

The effect of the fungus on mite fecundity

To attain a cohort of young mated females with an approximately equal age distribution (±12 hr) we placed twenty fecund females on a medium of freshly prepared peanut paste to oviposit for 24 hours yielding a few hundred eggs (following which the adult mites were removed). Adult males and females developed within 15 days at which point they were placed in groups of ten (five males and five females) in 16 mm diameter wells (Greiner Bio one - Cellstar) for five days with sterilized distilled water only (adding 60 µl of sterilized distilled water every 48 hr) allowing them to mate and clear their gut from the rich peanut diet.

For onion sprout fungal inoculation, in parallel to the preparation of the cohort of young mated females, onion seeds were allowed to germinate on wetted filter paper for one week in four 9-cm Petri dishes (16 seeds/dish). Half of the sprouts were then transferred to two Petri dishes containing potato dextrose agar (PDA) inoculated eight days earlier with *F. oxysporum*, while control sprouts continued to grow on water only. After three days the onion sprouts were transferred individually to 5-cm Petri dishes lined with wet filter paper.

Then to assess the effect of the fungus on mite fecundity, the starved young mated females were placed singly in 5-cm Petri dishes on wet filter paper together with fungal-infested or non-infested onion sprouts, 30 dishes per treatment, each dish being a replicate. After five days the experimented ended with the total count of eggs per dish giving the mean fecundity for five days. The experimental setup was thought to be very suitable for this evaluation as all females were found alive and well at the end of the five day trial. A t-test was used to assess the effect of the fungus on mite fecundity.

The effect of the fungus and the mite on onion rootlet growth

To study the effect of mites and fungus on sprout rootlet growth, fungal-infested and non-infested sprouts were prepared as described above (see fungal effect on mite fecundity). Adult female mites were taken directly from the rearing stock. Four treatments (10 replicates) were evaluated: 1) non-infested onion sprouts with 20 mites placed in the centre of the Petri dish (not on the onion sprout), 2) fungal-infested onion sprouts, 3) fungal-infested onion sprouts with 20 mites (same mite setup as treatment 1), 4) non-infested onion sprouts without mites as a negative control. Once a day (for four days) all dishes were photographed with a digital camera, using the macro mode (Nikon 5600 Coolpix). Daily rootlet growth was measured.
from the digital images using an Olympus Soft Imaging System (www.olympus-sis.com). All data were analyzed with a one way ANOVA repeated measures analysis (SPSS 14.0).

**Results and discussion**

After 8 weeks, the survival of the potted seedlings was reduced by the mite (F<sub>1,25</sub>=7.24; P=0.013) and fungus (F<sub>1,25</sub>=5.44; P=0.026), while the interaction (mite × fungus) had no significant effect (F<sub>1,25</sub>=1.58; NS; Table 1). Seedling survival was highest in the control and did not differ from the fungal treatment. Potted plants with mites and the treatment combining the mites and the fungus significantly lowered seedling survival compared to the control, with no significant difference between the three treatments.

Table 1. Onion seedling survival eight weeks post infestation of *Fusarium oxysporum* (4x10^5 conidia/pot) and *Rhizoglyphus robini* (100 females/pot).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Survival %</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Fusarium oxysporum</em> &amp; <em>Rhizoglyphus robini</em></td>
<td>80.2 b</td>
</tr>
<tr>
<td><em>Rhizoglyphus robini</em></td>
<td>83.3 b</td>
</tr>
<tr>
<td><em>Fusarium oxysporum</em></td>
<td>84.4 ab</td>
</tr>
<tr>
<td>Control</td>
<td>94.8 a</td>
</tr>
</tbody>
</table>

Mite fecundity on onion sprouts was nearly six times higher on onions infected with *F. oxysporum* (T<sub>58</sub>=6.147). Mean fecundity for the five day period was 34.6 eggs on infested-plant compared to 5.6 eggs on non-infested plants. It should be noted that the mites were starved for five days prior to this evaluation, which is evidently the reason why the fecundity levels are low in both treatments.

Repeated measure analysis of the Petri dish experiment showed that after 4 days rootlet growth was significantly affected by time (F<sub>3,108</sub>=39.56, P<0.001), treatment (F<sub>3,36</sub>=33.08, P<0.001), and by interaction time × treatment (F<sub>9,108</sub>=16.73, P<0.001) (Figure 1). Rootlet length of sprouts exposed to the fungus was significantly lower than that of the control and mite treatments, which were similar and significantly higher than the combination treatment of mites and fungus, the latter having the worst effect.

The association and interactions between various fungi and *R. robini* have been reported for various crops such as lily (Ascerno et al., 1981) and rakkyo (Allium chinense) (Shinkaji et al., 1988; Okabe & Amano, 1991). These studies focused on highly pathogenic fungi with bulbs as the subsoil site of infestation for pathogens and mites, whereas, in the present study we have evaluated the interaction between a weakly-pathogenic strain of *F. oxysporum* and onion grown from seed.

The effects of the fungus and mite on onion sprout survival in our 8 week potted plant experiment although significant were subtle, whereas in the Petri dish experiment a severe effect was detected in only 4 days. These differences may be explained by the different fungal inoculation methodologies used in each experimental setup. We also suspect that the non-sterile conditions of the long term potted plant experiment allowed for the infestation of other fungi, which may have affected the outcome of the experiment. In the Petri dish evaluation, the fact that the mites alone had no effect on rootlet growth, in contrast to the immense effect of the combined treatment of the mites and the fungus further strengthens the hypothesis that
the mite will only become a pest if a suitable pathogen is present. Obviously these issues become far more complex in the field and therefore we insist that more research should be conducted to develop soilborne pathogen control strategies, which would subsequently make the plant less attractive and less susceptible to bulb mite attack.

Figure 1. The effects of *Rhizoglyphus robini*, *Fusarium oxysporum* and their combination on mean rootlet length of onion sprouts contained in a Petri dish over a 4 day period.

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**References**


Results of a survey on plant protection in organic nursery production in Germany

Martin Hommes, Julianna Bors, Katharina Raupach, Sabine Werres
BBA, Institute for Plant Protection in Horticulture, Messeweg 11-12, D-38104 Braunschweig, Germany, E-mail: m.hommes@bba.de

Abstract: In Germany a survey relating to plant protection in 31 organic production nurseries was conducted in 2003. At that time 44 nurseries were run organically. The survey was carried out by interviewing the nurserymen on their premises. The organic production nurseries were very heterogeneous in size and structure. Nearly all growers inspected their crops regularly for plant diseases, pests, and weeds. If plant protection problems arose, nurserymen consulted primarily technical literature or asked other colleagues. The occurrence of economically significant causes of damage varied very much from nursery to nursery. A great range of different disease species were recorded by the growers without indicating a particular one. In contrast sucking insects like aphids and scale insects, vertebrates, spider mites and black vine weevils were mentioned as pests playing a major role. Common couch and creeping thistle were reported as weeds difficult to control. The most important criteria for controlling weeds, pests and diseases were economic thresholds, tolerance by the customer and operating procedures. A systematic change of plant selection was an important instrument in organic nursery production to avoid or minimise infestations with viruses and pests. In existing stock, nurserymen controlled harmful organisms and undesired weeds by various preventive and direct measures. Growers take a lot of different measures to encourage the occurrence of beneficials. They set up additional food sources and refuges with hedges, green fallow, tolerating weeds and wood or stone piles.

Key words: survey, organic nursery production, plant protection

Introduction

In the last decade the demand for organically produced products especially in the food sector have increased enormously in Germany and many other countries (Willer & Yussefi, 2007; www.organic.aber.ac.uk/statistics/europe05.shtml). One of the reasons for this development in our country is the recurrent negative headlines on pesticide residues in vegetables and fruits (www.greenpeace.de/themen/chemie/pestizide_lebensmittel/). In the long term the production of ornamentals including hardy nursery stock could benefit in the same way as the food sector. Therefore the objective of the survey was to analyse the actual situation for organic production nurseries. Data needed to be compiled on plant protection problems and control measures as a basis for future research strategies and political advisory work.

Material and methods

Survey

With the help of different organisations, professional journals, extension service and through internet inquiries an actual list of organic production nurseries was generated. A special questionnaire was developed for nurserymen. This questionnaire was sent prior to growers and was the basis for the interview on their premises. Thirty one of 44 nurseries participated in the survey.
Results and discussion

Information on the survey and on organic nursery production

In Germany a survey relating to plant protection in organic production nurseries was conducted in 2003. At that time 44 nurseries were run organically. 37 of them, which is equivalent to 1.1% of all nurseries in Germany, were certified according to the EC-Eco-Directive (EEC No. 2092/91). Thirty-one nurseries agreed to participate in the survey. The survey was carried out by interviewing nurserymen on their premises. The full results of the survey were published in a separate booklet of the Federal Biological Research Centre (Bors et al., 2006). In this paper only some of the results of the investigations are presented.

The organic production nurseries in Germany were very heterogeneous in size and structure. Over two-thirds of the 31 enterprises were mixed-stock nurseries and offered a great variety of woody plants. Most nurseries were retailers, adjusting their supply to the demands of the local market. Cultivation methods of half of the nurseries were similar to conventional nursery practices. Nearly all nurserymen inspected their crops regularly for plant diseases, pests, and weeds. If plant protection problems arose, growers consulted primarily technical literature or asked colleagues. Consultants were asked for help much less frequently and provided their assistance mainly on the telephone, as this form of consultation was preferred.

Economically important diseases and pests

When growers were asked which are the most important diseases and pests in their nursery the answers differed greatly (Table 1 and 2). Concerning diseases, 11 economically important ones were mentioned (Table 1). None of them played an extraordinary role. In contrast 4 of the 13 economically important pests recorded in Table 2 played a major role. In the first place sucking insects like aphids were mentioned by 68% of the nurserymen, followed by vertebrates (36%), spider mites and black wine weevils (each with 16%). The weeds mentioned as difficult to control were common couch and creeping thistle.

Table 1. Economically important diseases from growers view.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Attacked crops</th>
<th>% farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plum pox potyvirus</td>
<td>Plum</td>
<td>4</td>
</tr>
<tr>
<td>Stigmina carpophila</td>
<td>Cherry, Prunus laurocerasus</td>
<td>8</td>
</tr>
<tr>
<td>Phragmidium mucronatum</td>
<td>Rosa spp.</td>
<td>4</td>
</tr>
<tr>
<td>Gymnosporangium sabinae</td>
<td>Pear</td>
<td>4</td>
</tr>
<tr>
<td>Phloesospora padi</td>
<td>Cherry, Tilia spp.</td>
<td>4</td>
</tr>
<tr>
<td>Monolinia laxa</td>
<td>Sweet cherry, flowering cherry</td>
<td>4</td>
</tr>
<tr>
<td>Phytophthora cactorum</td>
<td>Apple</td>
<td>4</td>
</tr>
<tr>
<td>Diclocarpon rosae</td>
<td>Rosa spp.</td>
<td>8</td>
</tr>
<tr>
<td>Damping off</td>
<td>Several crops</td>
<td>8</td>
</tr>
<tr>
<td>Leaf spots</td>
<td>Prunus spinosa, Tilia spp.</td>
<td>8</td>
</tr>
<tr>
<td>Bark disease</td>
<td>Crataegus spp.</td>
<td>4</td>
</tr>
</tbody>
</table>

Toleration of damage and criteria for control of weeds, pests and diseases

If the infestation levels were not too high, aphids could be tolerated by 48% of the growers,
followed by mildew diseases (26%) and weeds (26%). Damage caused by scab, biting insects and slugs and snails (each 4%) were tolerated to a much lower extent. The most important criteria for the control of weeds, pests and diseases were economic thresholds (97%), tolerance by the customer (57%) and operating procedures (38%).

Table 2. Economically important pests from growers view.

<table>
<thead>
<tr>
<th>Pests</th>
<th>Attacked crops</th>
<th>% farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slugs and snails</td>
<td>Several crops</td>
<td>8</td>
</tr>
<tr>
<td>Spider mites</td>
<td><em>Hedera</em> spp., <em>Ulmus</em> spp., <em>Rosa</em> spp.</td>
<td>16</td>
</tr>
<tr>
<td><em>Eriophyes</em> spp.</td>
<td>Pear</td>
<td>4</td>
</tr>
<tr>
<td><em>Otiorynchus</em></td>
<td>Several crops</td>
<td>16</td>
</tr>
<tr>
<td><em>Meligethes aeneus</em></td>
<td><em>Fagus</em> spp., <em>Tilia</em> spp.</td>
<td></td>
</tr>
<tr>
<td><em>Xeleborus dispar</em></td>
<td>Fruit trees, avenue trees</td>
<td>4</td>
</tr>
<tr>
<td><em>Caliroa annulipes</em></td>
<td><em>Tilia cordata</em></td>
<td>4</td>
</tr>
<tr>
<td><em>Hoplocampa</em> spp.</td>
<td>Gooseberry</td>
<td>4</td>
</tr>
<tr>
<td><em>Pristiphora abietina</em></td>
<td><em>Picea</em> spp.</td>
<td>4</td>
</tr>
<tr>
<td><em>Mikiola fagi</em></td>
<td><em>Fagus</em> spp.</td>
<td>4</td>
</tr>
<tr>
<td><em>Trialeurodes vaporariorum</em></td>
<td>Several crops</td>
<td>4</td>
</tr>
<tr>
<td><em>Cameraria ohridella</em></td>
<td><em>Aesculus hippocastanum</em></td>
<td>4</td>
</tr>
<tr>
<td>Sucking insects (aphids, scale insects)</td>
<td>Fruit trees, <em>Fagus</em> spp., <em>Rosa</em> spp.</td>
<td>68</td>
</tr>
<tr>
<td>Caterpillars</td>
<td>Several crops</td>
<td>8</td>
</tr>
<tr>
<td>Voles, birds, game animals</td>
<td>Several crops</td>
<td>36</td>
</tr>
</tbody>
</table>

Preventative measures to avoid infestations and methods for enhancing beneficials

A systematic change of plant selection was an important instrument in organic nursery production to avoid or minimise infestations with viruses and pests. In existing stock, nurserymen controlled harmful organisms and undesired weed cover by various preventive and direct measures (Table 3). Plant disease problems were a significant limiting factor for the variety of woody plants cultivated in organic nurseries. Nearly two-thirds of the interviewed nursery managers had to remove sensitive species and varieties from their selection of woody plants – particularly orchard trees and ornamentals – due to phytopathogenic problems. Advisors stated that roses and fruit trees, especially, cannot be produced organically with economic success due to problems with phytopathogenic organisms. According to the majority of the organic production nurserymen and advisors, it is not possible to economically cultivate the same wide range of woody plants as is grown using conventional nursery production methods.

Growers utilise a lot of different measures to enhance the occurrence of beneficials (Table 4). Additional food sources were provided by setting up hedges, green fallow and tolerating weeds. Refuges were most frequently provided by hedges and wood or stone piles. 67% of nurserymen stated that they have more beneficials after the conversion to organic production than before.

One of the results of the survey was also that nurserymen would especially like to receive better support for marketing and plant protection problems from politicians and researchers.
Table 3. Preventative measures.

<table>
<thead>
<tr>
<th>Cultivation methods</th>
<th>% farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site selection</td>
<td>80.6</td>
</tr>
<tr>
<td>Site improvement</td>
<td>74.2</td>
</tr>
<tr>
<td>Soil improvement</td>
<td>87.1</td>
</tr>
<tr>
<td>Mulching</td>
<td>58.1</td>
</tr>
<tr>
<td>Undersowing</td>
<td>41.9</td>
</tr>
<tr>
<td>Crop rotation</td>
<td>77.4</td>
</tr>
<tr>
<td>Optimal plant space</td>
<td>83.9</td>
</tr>
<tr>
<td>Use of healthy seed and propagation material</td>
<td>96.7</td>
</tr>
<tr>
<td>Use of tolerant varieties</td>
<td>71.0</td>
</tr>
<tr>
<td>Eradication of infestation foci, alternative and intermediate hosts</td>
<td>74.2</td>
</tr>
<tr>
<td>Cleaning and disinfection of hard surfaces, culture vessels, knives, etc.</td>
<td>41.9</td>
</tr>
<tr>
<td>Substrate steaming</td>
<td>19.4</td>
</tr>
</tbody>
</table>

Table 4. Measures for enhancing beneficials.

<table>
<thead>
<tr>
<th>Measures</th>
<th>% farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food sources</td>
<td></td>
</tr>
<tr>
<td>Hedges</td>
<td>93.5</td>
</tr>
<tr>
<td>Tolerance of “weeds”</td>
<td>71.0</td>
</tr>
<tr>
<td>Green fallow</td>
<td>61.3</td>
</tr>
<tr>
<td>Flower stripes</td>
<td>48.4</td>
</tr>
<tr>
<td>Flowering under sown crops</td>
<td>41.9</td>
</tr>
<tr>
<td>Flowering intercrops</td>
<td>35.5</td>
</tr>
<tr>
<td>Early provision of pollen in spring</td>
<td>35.5</td>
</tr>
<tr>
<td>Refuges</td>
<td></td>
</tr>
<tr>
<td>Hedges</td>
<td>93.5</td>
</tr>
<tr>
<td>Wood pile</td>
<td>71.0</td>
</tr>
<tr>
<td>Stone pile</td>
<td>64.5</td>
</tr>
<tr>
<td>Building up special biotopes (e.g. wetland)</td>
<td>64.5</td>
</tr>
<tr>
<td>Nesting boxes for birds</td>
<td>58.1</td>
</tr>
<tr>
<td>Perches for birds of prey</td>
<td>48.4</td>
</tr>
</tbody>
</table>

Acknowledgements

We thank the Federal Ministry of Food, Agriculture and Consumer Protection for financial support and all the nurserymen for their participation in the survey.

References

Alternative food sources to enable establishment of *Amblyseius swirskii* (Athias-Henriot) on chrysanthemum without pest presence

Hans Hoogerbrugge, Yvonne van Houten, Elmer van Baal, Karel Bolckmans
Koppert Biological Systems, P.O. Box 155, 2650 AD Berkel en Rodenrijs, The Netherlands, E-mail: hhoogerbrugge@koppert.nl

Abstract: Seven alternative food sources; cysts of the brine shrimp *Artemia* sp. (Branchiopoda: Artemiidae), honey bee pollen, *Carpoglyphus lactis* (Acarina: Acaridae), *C. lactis* + diet A, diet B, diet B + honey bee pollen and eggs of the Mediterranean flour moth, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) + fresh corn pollen were tested in a cage experiment on young chrysanthemum plants to check if it had a positive effect on the population development of *Amblyseius swirskii*. The results showed that there is a positive effect in the treatments where *E. kuehniella* eggs + fresh corn pollen and *C. lactis* were added on to the plants. When *C. lactis* was released on the plants in combination with diet A it resulted in a significantly higher population of *C. lactis* and *A. swirskii* on the plants than the treatments with only *C. lactis*. The treatments with cysts of *Artemia* sp., honey bee pollen, diet B and diet B + honey bee pollen resulted in only a slightly higher population of *A. swirskii* compared to the untreated control.

Key words: *Amblyseius swirskii*, *Carpoglyphus lactis*, *Ephestia kuehniella*, *Artemia* sp., pollen, alternative food, chrysanthemum

Introduction

The generalist predatory mite *Amblyseius swirskii* (Athias-Henriot) (Acari: Phytoseiidae) is widely used by greenhouse growers since its introduction in 2005 (Bolckmans *et al*., 2005). This predatory mite establishes well on pollen producing crops like sweet pepper (*Capsicum annuum*) (Hoogerbrugge *et al*., 2005) which makes it possible to release it prior to the appearance of pests. Although the fact that chrysanthemum (*Chrysanthemum* sp.) is a flowering and pollen producing crop, in practice the pollen is not useful for *A. swirskii* simply because the plant starts flowering just before it is harvested, 9 to 10 weeks after the cuttings are planted. Predatory mites are mainly released between the 2nd and 7th week after planting. At that time pollen is not available. Also the pest density is normally too low to enable and maintain establishment of predatory mites.

At this moment growers can choose between 2 systems to maintain *A. swirskii* in the crop. One system is to use slow release sachets and the other system is a frequent release of predatory mites by using an air blower (van Schelt *et al*., 2008). With both systems it is possible to maintain a certain level of *A. swirskii* in the crop, depending on the release rate and release frequency. However, both systems do not result in an established population in the crop because the predators can hardly find any food and therefore will not reproduce sufficiently. The reason is that the tolerance for thrips in chrysanthemums is very low, the availability of food is the limiting factor for maintaining a population of predatory mites in the crop which is sufficiently high to keep the population of thrips at a minimum level. The idea behind this experiment is to provide an alternative food source on the plants which is suitable of *A. swirskii* resulting in reproduction of the predatory mite and therefore an increase of its population. In search for an alternative food source that could improve establishm on
the crop, seven different food sources were tested; cysts of the brine shrimp *Artemia* sp. (Arijs & De Clercq, 2001), honey bee pollen, *Carpoglyphus lactis* (Acarina: Acaridae), *C. lactis* + diet A, diet B, diet B + honey bee pollen and eggs of the Mediterranean flour moth, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) + fresh corn pollen (Swirskii *et al*., 1967; Castagnoli *et al*., 1999).

**Material and methods**

*Cage experiment*

The experiment was done in 8 cages (3 × 1 × 2 m) in an experimental greenhouse. 4 pots with each 4 chrysanthemum (cultivar “Raegan”) cuttings were placed in each cage, resulting in a total of 32 pots with chrysanthemum cuttings. A single pot with 4 chrysanthemum plants was seen as one replicate. To prevent predatory mites from migrating from one pot to another, each pot was placed in a bucket with water and soap. The plants did not touch the sides of the cages nor the plants in the other pots in the cage.

After 2 weeks the cuttings were developed to small plants with an average of 11 leaves per plant. When the plants had reached this age and size, 10 mated female *A. swirskii* were released on every plant (day 0). Just before releasing the predatory mites the alternative food was sprinkled over the plants. Food was sprinkled *ad libitum* over the plants on day 0, 7, 14 and 24. The food sources being tested are listed in Table 1. The plants in this trial were irrigated with a drip irrigation system. No overhead irrigation was used and therefore the plants themselves remained dry during the experiment.

**Table 1. List of alternative food sources tested.**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Description in figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Cysts of the brine shrimp <em>Artemia</em> sp.</td>
<td><em>Artemia</em> sp.</td>
</tr>
<tr>
<td>2. Grinded dry pollen (collected by honey bees)</td>
<td>Honey bee pollen</td>
</tr>
<tr>
<td>3. <em>Carpoglyphus lactis</em> (mixture of all stages)</td>
<td><em>Carpoglyphus lactis</em></td>
</tr>
<tr>
<td>4. <em>Carpoglyphus lactis</em> (mixture of all stages) + diet A</td>
<td><em>C. lactis</em> + diet A</td>
</tr>
<tr>
<td>5. Diet B</td>
<td>Diet B</td>
</tr>
<tr>
<td>6. Diet B + grinded dry pollen</td>
<td>Diet B + honey bee pollen</td>
</tr>
<tr>
<td>7. <em>Ephestia kuehniella</em> eggs + fresh corn pollen</td>
<td><em>Ephestia</em> + corn pollen</td>
</tr>
<tr>
<td>8. No alternative food</td>
<td>Untreated control</td>
</tr>
</tbody>
</table>

The *A. swirskii* population was monitored on days 14 and 28 by randomly picking 10 leaves from each replicate. The picked leaves were nearly full grown leaves between the middle and the top of the plant. The leaves were assessed with a binocular microscope. All stages of *A. swirskii* and *C. lactis* were recorded separately. Spontaneously occurring pests were also recorded.

**Results and discussion**

Addition of alternative food by using cysts of *Artemia* sp., grinded dry honey bee pollen, diet B, diet B + grinded dry honey bee pollen gave only a slightly higher *A. swirskii* population compared to the untreated control where no predatory mites were found. The *A. swirskii* population did not increase in these treatments between the first (14 days after release) and the
second (28 days after release) observation. Both treatments with *C. lactis* and the *E. kuehniella* + corn pollen treatment showed an increase of the *A. swirskii* population. 28 days after release of the predatory mites, the *A. swirskii* population was significantly higher compared to the untreated control (Figure 1) The combination of *C. lactis* + diet A resulted in a higher population of *C. lactis* (Figure 2). This treatment resulted by far in the highest *A. swirskii* population at the end of the trial. One thrips larva was the only occurring pest that was found in all the observations.

Based on these results, the use of *C. lactis* (with or without diet A) and the combination of *E. kuehniella* + fresh corn pollen can be considered as a promising option to get a better establishment of *A. swirskii* in a chrysanthemum crop or other non pollen producing crops.

![A. swirskii population](image)

Figure 1. Mean number of *A. swirskii* per leaf (95% CI for the mean), 14 and 28 days after release. Means at 28 days after release followed by different letters are significantly different (One-way ANOVA, \( P=0.000 \)).
Figure 2. Mean number of *C. lactis* per leaf (95% CI for the mean), 14 and 28 days after release of *A. swirskii*. Means at 28 days after release followed by different letters are significantly different (One-way ANOVA, P=0.001).

References


The potential of eggplant as a trap crop for the management of *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae) on poinsettia

Doo Hyung Lee, Jan Nyrop, John Sanderson
Department of Entomology, Cornell University, Geneva, New York 14456, USA; Department of Entomology, Cornell University, Ithaca, New York 14853, USA, E-mail: dl343@cornell.edu

Abstract: Eggplant, *Solanum melongena* L. was tested as a trap crop for the management of the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) on poinsettia, *Euphorbia pulcherrima* Wild. ex Koltz. In an experimental greenhouse, 70 poinsettias were placed in a 9×8 rectangular formation with 2 eggplants in the middle of the poinsettias. Two-thousand whitefly adults were released from the outside of the rectangular plot to test whether eggplant would attract whiteflies from poinsettias. The presence of eggplant remarkably changed the spatial distribution of the whiteflies resulting in a high level of aggregation on the eggplant. At 24h after release, 39 and 66% of the whiteflies were observed on the 2 eggplants in the 1st and 2nd trials, respectively. At 72h after release, the proportions increased to 66 and 83% in the 1st and 2nd trials, respectively.

Key words: *Trialeurodes vaporariorum*, trap crop, eggplant, poinsettia

Introduction

Several whitefly species (Homoptera: Aleyrodidae) are well-known, highly polyphagous insect pests (van Lenteren & Noldus, 1990). Conventionally, whitefly management has relied mainly upon the synthetic insecticide applications. This resulted in the surge in resistance by whiteflies to many insecticides which might be responsible for the outbreaks of whiteflies in various crop systems.

Interest in trap cropping has considerably increased in an effort to find an alternative to chemical-based pest control (Shelton & Badenes-Perez, 2006). A trap crop is a preferred host plant that is used to draw insect pests away from a less-preferred main crop (Vandermeer, 1989). Recently, Murphy (2007) tested in commercial greenhouses the use of eggplant, *Solanum melongena* L. as a trap crop for controlling whiteflies on poinsettia, *Euphorbia pulcherrima* Wild. ex Koltz. He tested the trap crop system in combination with the augmentative release of whitefly parasitoids. He documented a successful use of eggplants for the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), but only a limited potential for the silverleaf whitefly, *Bemisia argentifolii* Bellow & Perring.

While there is some evidence that trap crop systems have potential for the whitefly management (Al-Musa, 1982; Schuster, 2004; Murphy, 2007), several questions need to be answered before recommending this approach to growers on a general basis. These questions are mainly related to behavioural/ecological interactions between trap crop and whitefly. In our current project, we have tested eggplant as a trap crop for whitefly management on greenhouse poinsettia. In this paper, we present one data set from our choice experiments between eggplant and poinsettia. We examined in an experimental greenhouse whether eggplant is more attractive than poinsettia to adult greenhouse whiteflies.
Materials and methods

The experiment was conducted in an experimental greenhouse (8×6.5 m) at average 25°C and under a 14:10 (L:D) photoperiod. In the greenhouse, 70 poinsettias (cv. Prestige/Freedom Red; average 42 cm high) and 2 eggplants (cv. Baby Bell; average 35 cm high) were placed in a 9×8 rectangular formation (Figure 1). Two-thousand greenhouse whitefly adults (mixed age and sex) were collected in eight 25 ml glass vials (250 individuals per vial) from the laboratory colony at the Insectary, Cornell University. The colony was maintained on Kentucky wonder bean, *Phaseolus vulgaris* L. in a walk-in growth chamber at 25°C and under a 14:10 (L:D) photoperiod. At the onset of the test, 2,000 whiteflies were released from the outside of the 9×8 rectangular plot (Figure 1). After 6, 24, 72, and 168h, the number of adult whiteflies on each plant was recorded by carefully lifting up the plant and counting the whiteflies on the underside leaves. The experiment was replicated two times.

![Figure 1. Diagram of the experimental plot.](image)

Results and discussion

A large number of greenhouse whitefly adults dispersed across the poinsettias from the release points to the eggplants within 24 h. Accordingly, the presence of eggplant remarkably changed the spatial distribution of the whiteflies resulting in a high level of aggregation on the eggplant (Figure 2). In the first trial, the mean number of whiteflies on the 2 eggplants increased from 12.0 to 137.5 between 6 and 24 h, while the mean number on the 70 poinsettias decreased from 13.0 to 6.2. This was equivalent to the increase by 251 in the total number of whiteflies on the eggplants, and decrease by 475 on the poinsettias. In the second trial, the whiteflies dispersed to the eggplants more rapidly than in the first trial: 45% of the total whiteflies were observed on the 2 eggplants only after 6 h.
Figure 2. Contour maps for the spatial distributions of the greenhouse whitefly adults over time.
This result suggests that eggplant may have potential as a trap crop for the greenhouse whitefly management on poinsettia. However, more manipulative experiments need to be conducted to determine whether the presence of eggplant would reduce the whitefly density on poinsettias compared to on poinsettias grown in monoculture. It is also important to test how the use of eggplant can mediate the tritrophic interactions including natural enemies of the whitefly. This question is directly related to the development of a banker crop system in which biological control agents can establish a reproducing population on the eggplant as well as search and attack whiteflies on the poinsettia.

References

Towards a robust IPM programme for organic tomato

Rob Jacobson
RJC Ltd, Milnthorpe Garth, Bramham, Yorkshire, LS23 6TH, UK, E-mail: rob.jacobson@tiscali.co.uk

Abstract: The demand for organic food is steadily increasing in the UK and it has become necessary to grow organic tomato crops on a larger scale to satisfy the requirements of retail outlets in urban areas. This paper describes the additional challenges to cost effective pest control in such crops and outlines the control measures, which have been built upon the IPM programme for conventional tomato crops. These measures include i) a new method of culling populations of *Macrolophus caliginosus* which prevents economic plant damage and allows the insect to be exploited as a valuable biocontrol agent, ii) physical means of preventing mealybugs becoming established on tomato crops, and iii) methods of recycling biocontrols from areas of surplus in commercial crops. The involvement of growers in the project ensured immediate industry uptake of the new ideas.

Key words: organic tomato production, IPM, *Macrolophus caliginosus*, mealybugs, leafminers, spider mites, woodlice, natural pyrethrins, *Diglyphus isaea*, *Phytoseiulus persimilis*

Demand for organic produce

Consumers in the UK are becoming increasingly aware of the quality of their food, the methods employed in its production and the use of artificial chemical inputs. Retailers began to respond to these changing attitudes in the 1990s by introducing crop production standards for their suppliers that included minimal use of pesticides (Hilborn, 1998). The standards have evolved over the last decade and now address many issues which impact on the environment (e.g Marks & Spencer “Field to Fork”, 2007). Conventional UK growers have welcomed these initiatives and many have been proactive in implementing new agronomic practices and means of ensuring complete traceability of all their produce. Consumers should therefore have no doubt about the quality of home grown fresh produce sold by UK retailers.

However, an increasing number of shoppers are beginning to look for food that has been produced to an organic standard (Waitrose, 2007). The term “organic” is defined by EU law and verified in the UK by certification bodies such as the Soil Association. In simplistic terms, “organic” may be defined as food production based on a healthy living soil without any synthetic inputs. It should be stressed that the Food Standards Agency, which is a UK government department set up to protect consumer interests in relation to food, does not consider there to be a significant difference in the nutritional value of conventional and organic foods (Waitrose, 2007). It is therefore presumed that informed consumers base their choice upon the belief that organic production is more in balance with the environment.

Practicalities of large-scale organic production

The rapidly increasing demand for organic produce has outstripped traditional supplies. While there is still a place for small growers to supply local markets, such enterprises can’t satisfy the demands of retailers in large urban areas. British tomato growers have responded to this demand and 5.4% of the national hectarage is now converted to organic production (Source:
Tomato Growers’ Association Statistics). The Wight Salads Group (WSG) has over 10 ha of glasshouses converted to organic production on the Isle of Wight alone and now supplies over half of all fresh organic tomatoes sold by the major UK retailers.

Organic production requires more careful planning than conventional production because there are no “quick fixes” in the form of chemical fertilisers and synthetic pesticides. This is generally reflected in the price of the produce; e.g. Waitrose (2007) justify the higher cost of organic products by explaining that i) production areas must go through a conversion phase, ii) organic farming practices produce lower yields and iii) are more labour intensive.

WSG highlighted some of the difficulties of growing large scale organic crops when they estimated that their losses due to pest attack initially exceeded £100k/ha/yr. These losses were largely attributed to Macrolophus caliginosus, mealybugs and leafminers. Furthermore, expenditure on IPM products was double that of WSG’s conventionally grown tomatoes.

The remainder of this paper outlines the means by which cost of pest management in UK organic tomato crops has been brought into line with conventional production.

**Fundamental differences between IPM in conventional and organic crops**

IPM is highly advanced in conventional UK tomato crops (Jacobson, 2004). The programme has been developed over 30 years and includes control measures against over ten individual species of pests. The control of each is achieved using primary and secondary measures. The primary measures are usually biological and suppress pest population growth throughout the season. The secondary measures have traditionally been target specific chemicals and are used to redress the balance between the pest and beneficial populations when damage approaches the economic threshold. The importance of IPM compatible chemicals to the uptake of IPM in conventional production should never be underestimated. Their availability has provided a “safety net”, thus reducing pressure on crop managers and the risk of failure.

IPM in organic tomato crops has benefited from previous work in conventional crops but there are two fundamental differences. First, synthetic chemicals are not allowed to be used as second lines of defence in organic systems. This removes the safety net and increases the risk of complete failure. Second, conventional crops are grown hydroponically while organic crops are grown in the soil. The latter provides opportunities for pests that do not exist in conventional production systems. In addition, organic production focuses on speciality cultivars, many of which are very susceptible to pests. For example, the economic viability of vine ripened/vine harvested tomatoes is seriously affected by the loss of individual fruit when M. caliginosus feed on trusses (Sampson & Jacobson, 1999). Furthermore, certain popular baby cherry (e.g. cv Piccolo), cherry (e.g. cv Conchita) and cocktail (e.g. cv Campari) are extremely vulnerable to foliar damage by leafminers and spider mites.

**Building on the established IPM programme for conventional crops**

The studies described below were largely done within the whole organic system in commercial crops. This immediately highlighted any interactions with current agronomic practice, which would have otherwise caused delays when the new technologies were transferred from the experimental to commercial environs. This approach created some challenges in terms of experimental design but they were overcome with the assistance of a biometrician and were far outweighed by the benefits of having industry participation.

*Macrolophus caliginosus*

While economic losses caused by foliar feeding pests can be difficult to quantify, the loss of
income due to premature fruit drop is indisputable. Prior to this project, WSG considered *M. caliginosus* to be their most serious pest. However, there was little doubt that the predator could make a useful contribution to IPM if its population could be subsequently manipulated to avoid injury to the plants.

Two approaches were considered. The first involved restraining the *M. caliginosus* population by keeping numbers of its invertebrate prey as small as possible. This proved to be complicated and fraught with problems. Furthermore, it prohibited the use of *M. caliginosus* as a biocontrol agent, which could assist suppression of leafminers and spider mites.

The second approach involved using an IPM compatible remedial treatment to cull the *M. caliginosus* population after pests had been controlled. Natural pyrethrins (as Pyrethrum 5EC), which are extracts of African chrysanthemums (*Chrysanthemum cinerarifolium*), were successfully tested against *M. caliginosus* in 2006 and the methods were refined in 2007. Although pyrethrins are fairly broad spectrum, their short persistence means they can be separated from natural enemies in time and/or space. For example, applications against *M. caliginosus* can be restricted to leaves above those upon which parasitic wasps are most active. Furthermore, the immature stages of most parasitoids are protected within their hosts.

As a consequence of this development, *M. caliginosus* is now used as a biocontrol agent against other pests in the knowledge that populations can be culled before crop damage occurs. This has led to a fundamental change in the overall IPM strategy for organic crops.

**Mealybugs**

Mealybugs (*Pseudococcus viburni*) were the second most economically damaging pest of organic tomato crops at the start of the project. More than twenty combinations of IPM compatible control measures had shown potential when tested against mealybugs in experimental situations but had failed at the population level in commercial crops. This was due to a combination of four factors: i) their cryptic nature, ii) the protection provided by waxy filaments, iii) their resilience in returning to plants after being knocked down by sprays, and iv) the great fecundity of survivors which allowed rapid recovery of populations.

Control measures based on spray applications of Eradicoat T, Savona, steam and/or natural pyrethrins were only partially effective. Trials with the parasitoids, *Leptomastix epona* and *Pseudaphycus maculipennis*, concluded that they were more likely to coexist with the pest than control it. Three species of nematodes (*Steinernema feltiae*, *S. carpocapsae* and *Heterorhabditis megidis*) failed to reduce population growth compared to untreated controls.

As there had been so much difficulty in achieving remedial control during the growing season, more emphasis was placed on minimising the numbers of mealybugs that survived between crops and successfully colonised the new plants. Detailed monitoring enabled us to predict the timing of mealybug invasion and showed that newly hatched nymphs used tomato volunteer seedlings as “refuelling stations“ on their way to the crop. A strategy based on the use of black-backed polythene soil covering to prevent tomato seedling growth and sticky barriers to intercept nymphs was very successful. The few mealybugs that reached the plants were controlled manually which proved more cost-effective than use of soft chemical sprays.

**Woodlice**

Populations of *Porcellio scaber* and *Armadillidium nasatum* commonly become very large in organic crops and individuals will climb plants to feed on stems and leaves. In the early season, this can seriously deplete foliage, while later in the year the stem damage can provide an entry point for secondary disease organisms. The predatory spiders, *Dysdera crocata* and *D. erythrina*, existed in the study crops and must have had some impact on the woodlice population. However, their long life cycle, slow population growth and low predation rate
proved inadequate to prevent woodlice numbers reaching damaging levels. Various other control measures, including parasitic nematodes and *Atheta coriaria* (boosted by feeding stations) were also evaluated without success. The most effective control measure tested to date has been ferric sulphate slug pellets (Ferramol), which are approved for use in organic crops. The search for other control measures continues.

**Spider mites and leafminers**

The management of spider mites (*Tetranychus urticae* and *T. cinnabarinus*) and leafminers (*Liriomyza bryoniae*) has been improved by fine tuning monitoring methods to more accurately time the release of *Phytoseiulus persimilis* and *Diglyphus isaea*. In addition, simple yet highly cost effective methods have been developed to collect both species of natural enemies from areas of surplus in commercial crops for release elsewhere. This has allowed the numbers of purchased natural enemies to be increased in the knowledge that much larger numbers can be harvested and redistributed later in the season. In effect, this strategy has created within-crop rearing units.

More emphasis is now placed on the contribution made by *M. caliginosus* to the control of spider mites and leafminers and trials have begun to establish the most cost effective method of releasing this predator in speciality tomato cultivars. It is interesting to note that this approach would not even have been considered by organic growers prior to the development of the method of culling *M. caliginosus* populations described above.

Although both pests can be controlled with biological control agents, there remains concern over the amount of foliar damage which often occurs before the pest populations are constrained. As a consequence, additional control measures are sometimes required. For example, sprays of the starch-based material, Eradicoat T, are occasionally applied to the tops of plants to reduce feeding damage and egg laying by adult leafminers. The same product is also used as spot sprays against the forms of spider mites that cause hyper-necrotic damage symptoms at very low population densities (Zhang & Jacobson, 2000).

**Acknowledgements**

The author thanks the Horticultural Development Council and WSG for jointly funding this work, Dr Phil Morley for agronomic inputs, Paul Howlett and Brian Moralee (all WSG) for their constructive ideas and willingness to host trials, and Dr John Fenlon (Warwick University) for his guidance on experimental design and statistical analysis.

**References**


Intraguild predation among biological control agents used in greenhouse floriculture crops: a preliminary review

Sarah Jandricic, John Sanderson, Steve Wraight
Cornell University, Department of Entomology, Ithaca, NY, 14850, USA, E-mail: jps3@cornell.edu; USDA-ARS U.S. Plant, Soil, and Nutrition Laboratory, Tower Rd., Ithaca, NY 14853, USA

Abstract: Literature on intraguild predation (IGP) in greenhouse floriculture (GHFC) was reviewed. Despite production practices that could increase the incidence IGP, no studies concretely showed that IGP disrupts GHFC biocontrol. Further studies need to include large-scale trials over entire crop cycles. However, based on studies to date, it appears that IGP effects are not sufficiently problematic to be of serious concern in GHFC, or can be surmounted by modifications in biocontrol practices.

Key words: intraguild predation, biological control

Introduction

Intraguild predation (IGP) (i.e. heterospecific organisms with the same prey engaging in trophic interactions) is now accepted to be a common occurrence. But because IGP consists of both resource competition and predation/parasitism, predicting its effects on biocontrol can be difficult. At best, releasing two biocontrol agents (BCAs) may increase pest suppression, despite IGP. At worst, it could disrupt biocontrol. In outdoor agroecosystems, the outcome can be altered by factors such as habitat, consumer behaviour and interactions with larger food webs (Daugherty et al., 2007). While greenhouses share some of these factors (e.g. the potential for alternative prey), they lack others (e.g. predation by higher consumers such as birds). Furthermore, GHFC growers commonly use augmentative biocontrol, in which additional numbers of selected species of BCAs are released as needed, unlike classical or conservation biocontrol on many outdoor crops. Therefore, IGP theories may need to be modified when it comes to the GHFC environment.

The incidence of IGP and its actual impact on herbivore suppression in GHFC biocontrol are not yet understood. Growers, researchers and consultants contacted for the purpose of this paper generally believe that IGP does occur in GHFC biocontrol, yet none were able to provide concrete examples or quantify its impact. The objective of this paper, therefore, was to review the literature on IGP interactions in the context of GHFC as a step in elucidating the significance of this phenomenon to the industry.

Material and methods

Examples of laboratory evaluations of IGP interactions involving commercially available GHFC BCAs are listed in Table 1. Data were drawn from the literature. This is not an exhaustive review, but examples from each of the major natural enemy guilds were included. Studies consisting only of no-choice trials were excluded. Results from the most predaceous life stage tested are given. IGP effects were characterized as “no effect” (<25% mortality), “low effect” (25-50%), “moderate effect” (50-75%), or “high effect” (>75%), based on IOBC
standards for assessing non-target effects of pesticides. In choice-based experiments the shared prey was the alternate choice. Equal numbers of both prey items were given unless otherwise indicated. Table 2 consists of data from cage or greenhouse experiments (though trials may have been conducted on non-floriculture crops). Small cage trials included at least 1 whole plant. Effects of using both IG BCAs on the target pest (compared to control with the IG prey alone) were listed as having a reducing, increasing, or neutral effect on pest densities.

Results and discussion

Literature trends

If only no-choice trials were considered, IGP would seem a potentially significant problem, assuming spatial and temporal coincidence of the BCAs. However, co-existence of IG BCAs should be possible if the IG predator prefers the shared prey over the BCA (Rosenheim & Harmon, 2006). Data in Table 1 support this. Predators attacking IG prey at high rates often had low to no effect once the target prey was introduced. Aphid BCAs may be an exception; even with choice, they more often than not caused moderate to high mortality. Lesser effects were seen with omnivorous and generalist predators, and with parasitoid IG prey (Table 2).

Table 1. Examples of IGP no-choice and choice lab trial. IGP effects were: “no effect” (<25% mortality), “low effect” (25-50%), “moderate effect” (50-75%), or “high effect” (>75%).

<table>
<thead>
<tr>
<th>Shared prey</th>
<th>Exploiter IG prey</th>
<th>Direct effect of IGP on IG prey stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No-choice lab-trials Choice lab-trials Reference</td>
</tr>
<tr>
<td><em>Macrosiphum euphorbiae</em></td>
<td><em>Coleomegilla maculata</em> (L3)</td>
<td><em>Aphidoletes aphidimyza</em> Eggs-late instars = high Late instars = high*</td>
</tr>
<tr>
<td><em>M. euphorbiae</em></td>
<td><em>Chrysoperla rufilabris</em> (L3)</td>
<td><em>C. maculata</em> Eggs-L4 = high L1 = high*</td>
</tr>
<tr>
<td><em>M. euphorbiae</em></td>
<td><em>Macrolophus caliginosus</em> (adult)</td>
<td><em>Episyrphus balteatus</em> Eggs = high Eggs = high*</td>
</tr>
<tr>
<td><em>Aphis gossypii</em></td>
<td><em>A. aphidimyza</em> (72h old larvae)</td>
<td><em>Aphidius colemani</em> Larvae (prior to mummification) = low Larvae (prior to mummification) = no effect</td>
</tr>
<tr>
<td>Aphid spp.</td>
<td><em>Chrysoperla carnea</em> (L3)</td>
<td><em>E. balteatus</em> Eggs = high Eggs = moderate*</td>
</tr>
<tr>
<td>Aphid spp.</td>
<td><em>Coccinella septempunctata</em> (L4)</td>
<td><em>E. balteatus</em> Eggs = high Eggs = no effect*</td>
</tr>
<tr>
<td>Bradysia spp.</td>
<td><em>Atheta coriaria</em> (adult)</td>
<td><em>Hypoaspis aculeifer</em> Eggs/nymphs = high Eggs = low</td>
</tr>
<tr>
<td><em>Tetranychus urticae</em></td>
<td><em>Orius tristicolor</em> (adult)</td>
<td><em>Phytoseiulus persimilis</em> Adults = high Adults = low*</td>
</tr>
<tr>
<td><em>Frankliniella occidentalis</em></td>
<td><em>O. tristicolor</em> (adult)</td>
<td><em>Amblyseius cucumeris</em> N2 = high N2 = moderate</td>
</tr>
<tr>
<td><em>F. occidentalis</em></td>
<td><em>Orius majusculus</em> (adult)</td>
<td><em>Iphiseius degenerans</em> Adults = low Adults = no effect*</td>
</tr>
</tbody>
</table>

Amount of shared prey offered was at least 50% greater than the amount of IG prey offered.
Table 2. Examples of IGP trials in small cages or under greenhouse conditions assessing effects on target prey density. Effects of using both IG BCAs (compared to control with the IG prey alone) are listed as having a reducing, increasing, or neutral effect on pest densities.

<table>
<thead>
<tr>
<th>Shared prey</th>
<th>Exploiter</th>
<th>IG prey</th>
<th>Effect of IG on target prey density</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bemisia tabaci</td>
<td>Delphastus catalinae</td>
<td>Encarsia formosa</td>
<td>Small cage trials Reduced</td>
<td>Heinz &amp; Nelson, 1996</td>
</tr>
<tr>
<td>B. tabaci</td>
<td>Verticillium lecanii</td>
<td>E. formosa</td>
<td>Greenhouse trials N / A Reduced</td>
<td>Jazzar &amp; Hammad, 2004</td>
</tr>
<tr>
<td>Liriomyza trifolii</td>
<td>Steinernema carpoeapsae</td>
<td>Diglyphus begini</td>
<td>Neutral</td>
<td>Sher et al., 2000</td>
</tr>
<tr>
<td>T. urticae</td>
<td>Orius laevigatus</td>
<td>P. persimilis</td>
<td>Neutral</td>
<td>Venzon et al., 2001</td>
</tr>
<tr>
<td>Tetranychus cinnabarinus</td>
<td>Neoseiulus californicus</td>
<td>P. persimilis</td>
<td>Neutral</td>
<td>Schausberger &amp; Walzer, 2001</td>
</tr>
</tbody>
</table>

**Issues affecting IGP in GHFC**

Several issues specific to GHFC could theoretically increase IGP compared to other cropping systems. The widespread use of multispecies assemblages (Meyling et al., 2002) increases the potential number of interactions. Also problematic is the simplified monoculture of GHFC plant communities: complex vegetation has been shown to mediate IGP by providing a refuge for IG prey (Finke & Denno, 2002). Furthermore, GHFC plants may have a bottom-up effect. Models predict that high quality plants increase variation in IGP with plant-feeding BCAs (e.g. Orius), thus increasing variation in the outcome of biocontrol (Gillespie & Roitberg, 2006). Also, little aesthetic damage is tolerated in GHFC. This requires the use of higher levels of BCAs, which could lead to inflated IGP, because population levels of shared prey can be relatively low. Despite these circumstances, IGP does not seem to have much overall effect when the small cage and greenhouse studies conducted to date are evaluated. According to the trends seen in Table 2, the benefit of releasing two IG BCAs (i.e. potentially reducing pest levels further) seems to outweigh the risk. No studies showed disruption of biocontrol. At worst, the effect was neutral, which may represent an unnecessary cost to the grower, but did not endanger the crop.

**Research needs**

The question of interest is whether IGP can affect biocontrol in GHFC. Alas, few large-scale trials have been attempted. Without realistic complexity, lab trials only indicate the possibility of IGP. There is also a need for trials that run the length of the crop cycle: most studies are too short to include multiple generations. Lab trials are still a necessary first screening tool, but only further greenhouse-scale manipulative experiments will adequately clarify whether IG interactions are significant in specific greenhouse biocontrol programs.

**References**


Influence of continuous lighting on the biology of *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae)

Nina Svae Johansen  
*Bioforsk Plantehelse, the Norwegian Institute of Agricultural and Environmental Research, Hoegskoleiveien 7, N-1432 Ås, Norway, E-mail: nina.johansen@bioforsk.no*

**Abstract:** In greenhouse rose production, there is a trend towards the use of extreme long days (up to 24 hours lighting) and high light intensity to reduce problems with powdery mildew. Continuous lighting has been found to have adverse effects on some insects as well. The effect of continuous lighting on the survival, development and fecundity of the greenhouse whitefly, *Trialeurodes vaporariorum* on cut roses was investigated in climatic chambers with artificial light at 21°C and 70% rh. Compared to whiteflies exposed to 20:4 hours L:D, whiteflies exposed to continuous lighting had lower egg and larval/pupal survival, and lower fecundity and female longevity. Egg and egg-adult developmental time was only slightly affected.

**Key words:** *Trialeurodes vaporariorum*, greenhouse whitefly, photoperiod, continuous lighting, roses, fecundity, development, survival

**Introduction**

The greenhouse whitefly, *Trialeurodes vaporariorum*, is an important pest in greenhouse cut rose production. A major obstacle for effective biological control of this pest is the treatment with fungicides and/or sulphur often necessary to control rose powdery mildew (*Sphaerotheca pannosa* var. *rosa*). Pettersen et al. (2006) showed that 24 hours lighting of roses reduced the problem with rose powdery mildew compared to 18 hours lighting. Further studies in the laboratory with rose leaves have shown that this is a direct effect of light duration on rose powdery mildew (Suthaparan, pers. com.). Combined with fluctuations in humidity, a good keeping quality of the roses can be obtained with continuous lighting (Pettersen et al., 2006).

The photoperiod plays an important role in the regulation of the behaviour, physiology, biology and diapause of insects (reviewed by Vänninen and Johansen (2005)). The diurnal alternation between photophase and scotophase is important for a normal function of the circadian clock in insects (Klowden, 2007), which can be disturbed by continuous light (Zdarek et al., 1992). There is little information on the effect of continuous lighting on the biology of herbivore insects, but adverse effects on reproduction and egg hatching have been found (Reinhold, 1998; Bebas & Cymborovski, 1999). Continuous lighting can also alter the properties of host plants (e.g. Patterson et al., 1994; Demers & Gosselin, 2002), and these changes might in turn influence the herbivore insect fitness.

To date, the performance of *T. vaporariorum* on roses has been little studied, and no investigations of the influence of continuous lighting on the biology of this pest have been done. This paper presents results from a study of the effect of continuous lighting on the survival, development and fecundity of *T. vaporariorum* on cut roses.
Material and methods

Insects and plants

*T. vaporariorum* was reared on cut roses (*Rosa* ‘Passion’) in a climatic chamber at 24°C, 70% rh and 20:4 hours L:D for several generations before onset of the experiments. Artificial lighting with a mixture of HPS and fluorescent light (272 W/m² installed) were given. The light intensity was 180 µmol PAR just above the closed plant canopy. The insects were not exposed to natural daylight.

Experimental conditions

The experiments were conducted in climatic chambers at 21°C and 70% rh, and under the same light quality and intensity as in the insect rearing, without natural daylight. Whiteflies were either exposed to 20:4 hours L:D (long day, light regime often used in greenhouse rose crops) or 24:0 hours L:D (continuous lighting). The two different lighting regimes were given in separate chambers, ensuring no light leakage between the treatments.

Immature survival and developmental time

Rose stems with young buds were used in the experiments. The 4th fully expanded leaf beneath the bud was put into a bag of insect net. Twenty to 30 adult whiteflies were transferred to the bag, and left for 24 hours to oviposit. Then the adults and the bags were removed, and the whiteflies went through the immature life stages on the rose leaf attached to the plant. To measure egg developmental time and survival, the leaf was cut off the plant and placed with the underside of the leaf facing upwards on water agar in a ventilated Petri dish 7 days after the eggs were laid. Number of hatched eggs was counted daily. To measure nymph developmental time and survival, the leaf was cut off 22 days after the eggs were laid, and number of hatched pupae was counted daily. Twenty-two (continuous lighting) and 30 (long day) kohorts of eggs, and 24 (continuous lighting) and 46 (long day) kohorts of nymphs, were observed.

Fecundity

Young leaf-lets from the long day and continuous lighting treatments were cut off and placed singly with the underside facing upwards on water agar in a ventilated Petri dish. One adult female and one male (< 24 hours old) were placed on the leaf-let and allowed to mate and oviposit. Number of eggs and adult survival were recorded daily. The leaf-lets were changed every 5th day, and the adults were carefully transferred to the new leaf. Twenty-nine pairs of adults were observed in each treatment.

Results and discussion

Immature and adult survival and fecundity were reduced in whiteflies reared under continuous lighting, compared to those reared under long day conditions. Egg survival was 76% at continuous lighting, and 93% at long day (Figure 1). Egg-adult survival was 45% at continuous lighting and 74% at long day. Egg and egg-adult developmental time was about 10 and 32 days, respectively, and was little affected by the lighting regime.

Longevity were reduced in females reared under continuous lighting compared to those reared under long day conditions (Figure 2), but the preoviposition and oviposition periods were not affected by the lighting regime. A little more than 50% of the female population reared under continuous lighting laid eggs and average number of eggs laid per female during
her lifespan was 22 (Figure 2). Under long day conditions, nearly 90% of the females laid eggs, and number of eggs per female was 53.

![Graph showing egg and egg-adult survival of *Trialeurodes vaporariorum* reared on roses under long day conditions or continuous lighting (mean ± SE).](image1)

Figure 1. Egg and egg-adult survival of *Trialeurodes vaporariorum* reared on roses under long day conditions or continuous lighting (mean ± SE).

![Graph showing fecundity and longevity of *Trialeurodes vaporariorum* females reared on roses under long day conditions or continuous lighting (mean ± SE).](image2)

Figure 2. Fecundity and longevity of *Trialeurodes vaporariorum* females reared on roses under long day conditions or continuous lighting (mean ± SE).

Malais and Ravensberg (2003) have reviewed survival, development, and fecundity in *T. vaporariorum* on different crops. Egg-adult developmental time found in our study was comparable to what has been found on *Gerbera* and tomato at 20°C and 16:8 hours L:D, and in beans at 21°C and 18:8 hours L:D (Stenseth, 1971), but the survival was 12-24% lower at 20:4 hours L:D, and 41-53% lower at continuous lighting. The fecundity at 20:4 hours L:D in
our study was comparable to what has been found on tomato, but lower than on aubergine and cucumber at 22°C.

The present study shows that continuous lighting has negative effects on the survival of all the life-stages of *T. vaporariorum*, and on the longevity and fecundity of females. Thus, continuous lighting could contribute to the control by lowering the fitness of the pest. However, larger scale experiments are needed to evaluate the practical value of such light treatment. Since the leaf-lets used in the adult test were given the same growing conditions prior to the experiments, the reduced fecundity is most likely caused by direct effects from the exposure to constant light. Whether the effects on the immature stages found in these experiments are caused by changes in the suitability of the host plant or by detrimental effects on the physiology of the pest is not known, and should be studied further.

*Encarsia formosa* is an important biological control agent used for the control of *T. vaporariorum*. We did some preliminary tests with *E. formosa*, which indicate that the parasitism rate and survival of the parasitoid is not affected by the lighting regime. However, if continuous lighting shall be used to help controlling powdery mildew and *T. vaporariorum* in roses, the impact on *E. formosa* and other biological control agents should be carefully evaluated.

Acknowledgements

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References


Synergistic interaction between parasitoids and sterile insects

R. Kaspi, M.P. Parrella
Department of Entomology, University of California, One Shields Avenue, Davis, CA 95616, USA, E-mail: rkaspi@ucdavis.edu

Abstract: We examine the hypothesis that the use of *Diglyphus isaea* for biological control of leafminers in greenhouse crops may be more practical and efficient when supplemented with additional control strategies, such as the Sterile Insect Technique (SIT). Our results validate previous theoretical models, and demonstrate synergistic control with releases of parasitoids (*D. isaea*) and sterile insects (*Liriomyza trifolii*). In light of these results, possible mechanisms underlying this synergistic interaction effect are discussed.

Key words: *Diglyphus isaea*, Sterile Insect Technique, synergistic interaction

Introduction

Augmentative releases of parasitoids and sterile insects as biological agents are commonly used as environmentally friendly control measures. Parasitoids and sterile males are mobile and highly potent in locating their target insects in their natural habitats. These two techniques may complement each other probably because they act on two different stages of the pest life-cycle; the sterile males reduce the reproductive potential of the adults, while most parasitoids attack immature stages (eggs, larvae or pupae). Some studies in field situations suggest that by using Sterile Insect Technique (SIT) together with parasitoid releases, better control was achieved than if either method were used alone (e.g. Bloem et al., 1998; Cossentine & Jensen, 2000). A few models predict mutual complementation (Barclay, 1987) and “mutual synergistic suppressive action” (Knipling, 1998a, b), although there is little empirical data to support these models. Here we experimentally demonstrate a synergistic interaction effect between releases of the leafminer larval parasitoid *Diglyphus isaea* (Walker) and sterile males of *Liriomyza trifolii* (Burgess) for controlling the *L. trifolii* population and speculate as to the underlying mechanism.

Material and methods

A 2x2 factorial design experiment was performed with four treatments (Figure 1): (I) parasitoids only (‘P’), (II) sterile males only (‘S’), (III) both parasitoids and sterile males (‘P&S’), and (IV) absence of both (control). Forty screen cages (86 ± 0.5 cm high × 28 cm diameter; containing five week old single chrysanthemum plants; var. 'Miramar') were placed randomly in a greenhouse (24 ±14°C). In each cage, seven female and five male leafminers were released. In the ‘S’ and ‘P&S’ cages, 25 sterile males (2-3 d old (Kaspi & Parrella, 2003)) were added for three successive weeks. Twelve days later, one pair of *D. isaea* was released per cage in the ‘P’ cages and ‘P&S’ cages. Twenty-two days later, all plants were cut, placed on the soil surface in the caged pot and two yellow sticky cards were placed inside the cages for four more weeks. They were then examined under a stereoscopic microscope, and the number of flies and parasitoids trapped was recorded.
Figure 1. *Liriomyza trifolii* populations. Horizontal lines denote the mean (± s.e.) and diamonds 95% confidence intervals. (a) mean number of adult flies per cage. Different letters indicate a significantly different means (Newman-Keuls test; \( P < 0.05 \)). (b) a hypothetical population size after four pest generations assuming there is no carrying capacity limitation, the number of parasitoid offspring per female equals the number of hosts killed by her, and 1:1 sex ratio for both the pest and parasitoid. Sterile males (fertile-to-sterile ratio 1:5) were added for two more generations to the ‘S’ and ‘P&S’ populations. The model is: \( N_t = 0.5N_{t-1} \alpha - 2P_t \Delta; N'_t = 0.5N'_{t-1}\alpha\gamma - 2P_t \Delta; P_t = 0.5P_{t-1}\beta \). Where \( N_t, N'_t, N_{t-1}, \) and \( N'_{t-1} \) are the pest population sizes in generation, \( t \) and \( t-1 \) respectively (\( N_t \) refers to the control and ‘*D. isaea*’ populations, \( N'_t \) refers to the ‘SIT’ and ‘IPM’ populations). Similarly, \( P_t \) and \( P_{t-1} \) are the parasitoid population size in generation \( t \) and \( t-1 \) respectively. \( \alpha \) is the mean observed pest fecundity and it is equal to 65.8 offspring per female. Similarly, \( \beta \) is the mean observed parasitoid fecundity and it is equal to 38.7 offspring per female. \( \gamma \) is a 64% reduction (i.e. \( \gamma = 0.36 \)) in offspring number caused by three releases of sterile males (5:1 sterile-to-fertile ratio). ‘2P’ is the total number of fly larvae that were killed by the parasitoid (in generation \( t \)) both by parasitism and host-feeding. Finally, \( \Delta \) equals zero for control and ‘SIT’ populations, and equals one for ‘*D. isaea*’ and ‘IPM’ populations.
Results and discussion

We found that the use of parasitoids together with sterile males (‘P&S’) was more efficient than the use of either method alone (ANOVA: \( F = 26.1, P < 0.0001 \); Figure 1a). The proportion of leafminer offspring killed by the parasitoid alone (‘Pp’) was 15.2% compared with the control. The proportion of leafminer offspring ‘eliminated’ by the sterile males alone (‘Ps’) was 64.0%. The expected proportion eliminated or killed by the parasitoids together with the sterile males (‘multiplicative risk model’ (Soluk & Collins, 1988)) is: \( P_{p+s} = P_p + P_s - P_pP_s = 69.47\% \). However, the observed proportion was 87.5%. In order to test this model, a two-way ANOVA on log-transformed data (log y) was used (Sih et al., 1998) and synergism was determined by testing the two-way ANOVA interaction effect (Sih et al., 1998; Slinker, 1998). We found a significant interaction between the two factors (parasitoids: \( F = 11.19, P = 0.0019 \); sterile males: \( F = 45.33, P < 0.0001 \); interaction: \( F = 7.47, P = 0.0096 \)). However, since one of the assumptions for parametric tests was violated, heteroscedasticity was best countered by using log(y + 36) transformed data (Mosteller & Tukey, 1977). The same results were obtained using this more conservative approach (parasitoids: \( F = 12.36, P = 0.0012 \); sterile males: \( F = 82.04, P < 0.0001 \); interaction: \( F = 5.92, P = 0.0201 \)). Moreover, a model based on our observed data predicts that due to the synergistic effect only the use of both methods will eradicate the pest population (Figure 1b).

Our results validate previous theoretical models, and demonstrate synergistic control with releases of parasitoids and sterile insects. This synergistic effect allows for complete population eradication. Our model, which is based on experimental observed data, predicts that using SIT approach alone or biological control alone may not control the pest population (Figure 1b). However, using a combination of these two approaches not only controls the pest population but completely eradicates the population due to the synergistic effect. The model results demonstrate an important feature of the SIT method, which unlike chemical control, becomes more effective as the wild population declines, provided a constant number of sterile males are released each pest generation. As the population declines, the ratio of wild to sterile males decreases, thus increasing the effectiveness of each release (Knipping, 1955, 1998a). This is one possible explanation for the synergistic interaction observed with releases of parasitoids and the SIT. However, we detected a significant synergistic effect in our experiment results that are based on a one-generation study. Another possibility is that the presence of a high leafminer adult population affected parasitoid behaviour in a way that increases its attacks or its host-feeding rate (oviposition and host-feeding patterns). We speculate that this altered parasitoid behaviour may be a perceived response to future host availability (i.e. future presence of high larva populations). This possible explanation however, remains to be validated.

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References


Occurrence and population trends of spider mite specialist predators under field and greenhouse conditions

Neda Kheradpir¹, Valliollah Baniameri², Mohammadreza Rezapanah²
¹Islamic Azad University, Science and Research Branch, Faculty of Agriculture & Natural Resources, Dep. Entomology, Po. Box 14155-4933, Tehran, Iran, E-mail: n.kheradpir@gmail.com; ²Plant Protection Research Institute (PPRI), Po. Box: 19395/1454 Tehran, Iran

Abstract: The objective of this study was to examine the population growth of spider mites in cucumber fields and greenhouses, followed by identification of the main specialist predators and monitoring their synchronization with prey population dynamics. The samples were taken for 150 days in spring and summer 2007 in two pilot plots in the Tehran Province. The results showed the predatory thrips, Scolothrips longicornis as a persistent predator in both conditions able to function at lower prey population densities than Stethorus gilvifrons. Good synchronization in both prey-predator populations showed the direct effect of prey availability on predator survivorship followed by direct and indirect effects of temperature.

Keywords: Scolothrips longicornis, Stethorus gilvifrons, population growth, Iran

Introduction

Carnivores that exploit patchily distributed herbivores have to move among prey patches to obtain sufficient prey for their survival and reproduction (Sabelis & van de Baan, 1983). During such inter-patch migration, predators benefit from detecting prey patches at a distance as they migrate into and out of greenhouses to search their host (Takahashi et al., 2001).

Different predator species that prey on spider mites, with different feeding habits from specialist to generalist, often coexist in the same field (Shimoda & Ashihara, 1996). They search for their hosts and preys according to different cues (Dicke & Vet, 1999).

Predator-prey models provide insight into how predator attraction and arrestment affect local population dynamics. In their simplest form, these models assume exponential growth of prey and predator population with a constant per capita predation rate (pancake predation models (Pels & Sabelis, 1999)). Sabelis et al. (1999) distinguished between three types of prey-predator dynamics: 1) continual increase, 2) initial increase followed by a decrease and 3) immediate decrease. Apart from the initial condition, assumptions on predator emigration appear to be critical. If predators emigrate during the interaction, type-3 will show up.

In this study, we investigated the seasonal occurrence of the dominant spider mite species Tetranychus urticae Koch (Acari: Tetranychidae) in a research field of cucumber and a greenhouse with the same cultivar in the Tehran province. Then we followed the population dynamics of the species and their synchronization until their disappearance. We hypothesize that predators follow their prey population and three questions arose to be answered: 1) which predators appear consistently on spider mites infested plants, 2) do predator populations synchronize with that of their preys, 3) do all developmental stages of prey and predators increase by the same rate?
Material and methods

A screening trial was conducted from May to October 2007 (20 weeks) to examine the population trends in the two spotted spider mite, *T. urticae* and its potential predators *Stethorus gilvifrons* Mulsant (Coleoptera: Coccinellidae) (in the field) or *Scolothrips longicornis* Priesner (Thysanoptera: Thripidae) (in the greenhouse) in cucumbers (*Cucumis sativus* cv. Sultan) in two areas. No fungicides or acaricides were used either in the field or in the greenhouse.

The samplings started in a cucumber field in the southeast of the Tehran Province, Varamin. The number of active mites plus eggs was counted with 10-day intervals by sampling either a fully expanded young leaflet (upper) or an old one (lower) from each cucumber plant. During eighty days (10th May – 30th July), nine samplings were performed. Twenty plants were sampled in each plot (20 plants × 2 leaves). The leaflets were examined microscopically and mites were counted in a 1-cm² area on each leaflet. On the same leaflets, the different developmental stages of predators were counted by the use of a 10x lens on the whole leaflet. Sampling was maintained until the predators disappeared and the plants in the field were harvested (July 2007). Temperature was recorded on each sampling date.

Sampling in the greenhouse started exactly 10 days after the field harvesting. The greenhouse was located in an area in north of Tehran (Velenjak, at PPRI campus) with an average of 5-10°C cooler than Varamin during the summer months. The same procedure for sampling was used with the time intervals decreased to 4 days (for predator monitoring) or 7 days (for *T. urticae*) giving a total of 10 samplings for *T. urticae* and twenty for the predators. Sampling continued into October at which time the predators disappeared completely.

An analysis of variance was done to compare mite levels and levels of its predators between dates and between young and old leaflets and for the different developmental stages. Due to the difference in sampling area for pest and predators, the data was converted to logarithmic scale.

Results and discussion

In field the dominant insect predator was *S. gilvifrons* while in greenhouse *S. longicornis* was the main biological agent. In the field both specialist predators were observed in addition to some generalist predators like *Orius niger* Wolff (Hemiptera: Anthocoridae) and a few chrysopid individuals (Neuroptera: Chrysopidae). A few numbers of the predatory mites *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) as well as *Orius* sp. were also recorded in the greenhouse. The population of predatory mites and *Orius* was very low and these species were consequently not included in the sampling program.

In the field, the population density of *S. gilvifrons* was at each sampling date 1.5-1.8 times higher than that of the second most abundant predator, *S. longicornis*, although the latter appeared sooner and disappeared immediately after the prey densities dropped to less than 0.01 mites per cm² leaf (Figure 1a). The patterns of population growth were the same for all the three species. In general, the populations of spider mites and its predators remained rather low throughout the sampling period with a slight increase on the warmest days of June and beginning of July (37±3°C), followed by a decline in populations on upper leaves. The lower leaves provided shade for spider mites and the predatory thrips both seemingly migrating to these plant parts to escape from warm weather and sunshine. However, populations were significantly higher on upper leaves before this increase in temperature (P<0.05).
For both the pest and the predatory thrips, the population dynamic followed the same pattern for all developmental stages, except for spider mites, which at the end of the field season showed significantly different oviposition rates. Apparently, the spider mites responded to the increase in temperature by producing more eggs. But following the decline in spider mites population, *S. gilvifrons* left the canopy and disappeared, perhaps caused by migration to adjacent infected fields or by as an escape from competitors (*S. longicornis*).

In the greenhouse, the spider mite population peaked (Figure 1b) in August when the temperature was at favourite levels for mites (30±2°C) hereby providing sufficient numbers of prey for the predators. In response to increasing numbers of *S. longicornis*, the other predator left the greenhouse due to low prey number (12.4±0.7 mites/cm²; Kheradpir *et al.*, 2006). In the greenhouse, the prey-predator interaction ended after 80 days when predators were no longer present, contrasting the situation in the field where predators persisted through to harvest. No significant differences (P>0.01) were found in the densities on lower and upper leaves so the results for whole plants were used for analyzing. The growth rate for the prey and the main predator *S. longicornis* showed great synchronization – for example when prey density increased from the initial 16±1.8 to 300±26 per two leaves per plant in 30 days, predator density increased from 1.2±0.7 to 9±2.3, the latter being due mainly to an increase in density of larvae. For the predator, the population increase was a result of ample supply of spider mites (43±1.8 mites/cm² at its peak) and a temperature stimulating oviposition.

Other similar studies have shown that the main predators in field and greenhouses infected by spider mites are different species of *Scolothrips* (Takahashi *et al.*, 2001) and *Stethorus* (Chazeau, 1974) in addition to *Orius* sp. as the main generalists (Baniameri *et al.*, 2006). Chazeau (1974) reported *S. gilvifrons* as the most effective spider mites predator with high temperature needs. Apparently in our greenhouse, the main factor to exclude this predator was low temperature (Roy *et al.*, 2002) and in the field, pest density was seemingly a limitation. In intra-guild predation interactions, the predatory thrips could win the competition with *S. gilvifrons* due to its lower feeding rate (Huffaker *et al.*, 1999). On the other hand,
Shimoda and Takabayashi (2001) mentioned the flight capacity of *S. longicornis* as the major reason for its ability to search out prey patches more efficiently than other specialist predators. The prey-predator population dynamic model in the greenhouse followed the type-3 (Sabelis *et al.*, 1999) and in the field we saw a smoothed type-3 of a longer duration. The specialist predators did not allow generalists to establish in the system. *S. longicornis* requires relatively few numbers of preys to survive, produces a high numbers of eggs (Gilstrap, 1995), has a high searching capacity and a good synchronization with its prey. These characteristics are the likely explanation for its effectiveness as a predator of spider mites in our experiments.

**References**


New dipteran pests in Belarus greenhouses

Tatiana P. Kondratenko
RUC “Institute of plant protection”, Laboratory of Microbiological Method, Minsk region, p. Priluki, Mira 2, E-mail: kondratenko-t@yandex.ru

Abstract: Data on the specific composition and monitoring of phytophagous Dipteran is presented in this article. In Belarusian greenhouses phytophagous insects of the Diptera order are widely spread. Some of the following species are present in all examined greenhouses: Bradysia brunnipes Mg., Bradysia fungicola Winnertz (Sciaridae), Scatella stagnalis Fll. (Eryhridae), Psychoda cinerea Banks, and Psychoda gemina Eaton (Psychodidae). An evaluation of monitoring methods for adult Diptera by the use of yellow sticky traps was done, revealing that a horizontal arrangement of traps results in higher catches. Notes on pest morphology and biology are given.

Key words: Diptera, Bradysia, Scatella stagnalis, Psychoda, pests, protected crops, cucumber, monitoring, yellow sticky traps

Introduction

Greenhouses are a special agroecosystems with year-round plant production sustaining specific pest complexes. The restricted composition of greenhouse crop species, the relatively constant abiotic factors, the absence of natural regulating factors significantly increase the seriousness of infestations with phytophagous insects and create special phytosanitarian situations. Monitoring of the species composition and population developments of pest complexes in protected crops is consequently of tremendous importance.

Recently the importance of phytophagous Dipteran in the Belarusian production of greenhouse vegetables has become apparent with especially the fungus gnat Bradysia brunnipes Mg. (Diptera: Sciaridae) being noted as a serious pest. However, other dipteran pests cause damage as well, e.g. to cucumber plants.

In the present study we studied the species diversity of phytophagous diptera in Belarusian greenhouses (Kondratenko, 2007) and examined ways for improving monitoring methods for evaluation of pest population densities and pest dynamics.

Material and methods

The monitoring of adult diptera was accomplished by the use of yellow sticky traps, a method widely used both for monitoring (Tron et al., 1997; Rice et al., 2001; Ahatov & Izhevskij, 2004; Pundt, 2006). Traps were placed at a density of 20 per hectare in a cucumber greenhouse and collected weekly. The catching efficiency of yellow sticky traps arranged either vertically glued over rockwool or placed horizontally between plants (Figure 1) was evaluated and compared.

Results and discussion

The catching efficiency of the yellow sticky traps depended on the way of spatial arrangement
with the horizontal arrangement resulting in higher catches of adult phytophagous dipterans than the vertical arrangement. The statistical method of analysis was T-test for Independent Samples \( (n_1 = 20, n_2 = 20, p\text{-level} = 0.00) \) (STATIATICA program).

![Figure 1. a. Vertical traps arrangement. b. Horizontal traps arrangement. Photo: T. Kondratenko.](image)

Besides the above-mentioned fungus gnat, *Bradysia brunnipes* Mg., the trap catches also included *Bradysia fungicola* Winnertz (Sciaridae), *Scatella stagnalis* Fill. (Ephydridae), *Psychoda cinerea* Banks and *Psychoda gemina* Eaton (Psychodidae), all of which are new to the Belarusian fauna of phytophagous dipteran.

**Fungus gnats**

Pests of the *Bradysia* genus belong to the Sciaridae family. Sciarids are fine medium sized (from 0.8 to 5-8 mm), dark-coloured insects (Figure 2a). The adults have spherical heads with the big facet eyes, forming an “eye bridge”, and 16-segmented antennae. The wings are brownish with nicely seen rear veins. The legs are elongated and stilts like (Bei-Bienko, 1969).

Female sciarids lay round semi-transparent eggs in groups up to 250. The larval length is nearly 5 mm with a black chitinized head and a cream semi-transparent body with a black translucent intestine. The larvae have a biting type of a mouth apparatus. Pupation takes place in damaged plant tissue or in the substrate. The whole cycle of sciarid development takes up to 26-30 days under temperatures of 18-20°C. In greenhouses up to 8 generations can develop within a year. Sciarids cause damage to cucumbers, tomatoes and many other greenhouse plants (Ahatov & Izhevskij, 2004) through larval mining of the roots, which eventually causes plant wilt and death. Sciarid larvae may also transmit fungal diseases such as *Botrytis, Fusarium, Phoma, Pythium* and *Thielaviopsis basicola*. Adult sciarid are able to transmit *Pythium, Fusarium* and *Verticillium* (Day, 1996).

**Moth flies**

Pests of the *Psychoda* genus belong to the Psychodidae family. The adults are fine dark or greyish flies up to 3 mm in length with bodies and wings densely covered by filaments. The wings take shape of a roof (Figure 2b). The females lay fine brown or cream-colored eggs in
irregular groups from 10 to 200. The larvae are legless, maggot-like, with a length up to 1 mm and of a greyish colour with dark ends. The head capsule is isolated and the mouth apparatus of the biting type. The life cycle takes from 1 to 3 weeks. A high activity is seen at nighttime. In greenhouses moth fly larvae may damage roots of greenhouse crops and may serve as vectors of diseases of the Fusarium genus (Dreistadt, 2001; El-Hamalawi & Stanghellini, 2004) Bronchial asthma can be caused by inhalation of dead insect imago (Lyon, 2000).

Shore flies
Adults of shore flies have reddish eyes, short legs and bristle-like tendrils (Figure 2c). Their wings are dark-grey with 5 light spots. The larvae are legless with a round brownish-yellow body up to 3 mm in length with characteristic posterior bisected inhalation tubes with dark-coloured ends (Dreistadt, 2001). The larvae can feed on plant roots infected by fungal diseases and are able to transmit Botrytis, Fusarium, Phoma, Pythium, and Verticillium (Rice et al., 2001). In addition the larvae feeds on decomposed organic substance, algae, bacteria, cyanobacteria and other microorganisms. Shore flies reproduce intensively under high moisture conditions and produce several generations per year (Dreistadt, 2001). Black spots of excrements left on plants by shore fly make production less attractive. In addition, high numbers of shore flies can become a nuisance to the greenhouse workers.

Figure 2. a. Adult fungus gnat. b. Adult moth fly. c. Adult shore fly. Photo: T. Kondratenko.

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References
Application methods for commercial biofungicides in greenhouses

Marja-Leena Lahdenperä, Maiju Korteniemi
Verdera Oy, Luoteisrinne 2, FI-02270 Espoo, Finland, E-mail: marja-leena.lahdenpera@verdera.fi

Abstract: There are several alternative ways of using biological fungicides, as for chemical pesticides. In this paper, the application methods of the biofungicides Mycostop® and Prestop®, developed by Verdera Oy in Finland, are presented. Mycostop® is based on the bacterium Streptomyces, while the Prestop® products contain the fungus Gliocladium catenulatum as the active ingredient. The performance of the products in practice has been studied using various crops and pathogens. In the case of Mycostop®, seed treatment was the most effective method for the control of damping-off, whereas incorporation into the growing medium turned out to be successful for the Prestop® formulations. The most practical way of controlling root and wilt diseases is to deliver Mycostop® and Prestop® by drip irrigation at regular intervals. Foliar diseases like Didymella bryoniae on cucumber and Botrytis cinerea on tomato can be controlled by sprayings directed to the site of infection.

Key words: biofungicide, biological plant disease control, application methods, Gliocladium catenulatum, Streptomyces sp.

Introduction

The application method plays an essential role in optimising of the use of biofungicides in commercial conditions. Biofungicides are mainly applied in the same way as the comparable chemical products. However, the involvement of living microbes sets special demands on the application method, which should allow rapid colonisation by the antagonist of the rhizosphere and the foliar surfaces.

The mode of action of most biological fungicides is preventative, which means that they have to be introduced at the early stages of plant growth, before the establishment of the pathogen. The first treatment is made by incorporation into the growing medium before sowing, or as a drench treatment at the seedling stage or at transplanting. As regards treatment of propagation material, seeds can be dressed and cuttings and bulbs can be dipped in an antagonist-containing suspension. For the control of foliar pathogens, the first treatment must be carried out as early as possible, and the following ones whenever the disease situation demands it or when the amount of the antagonist has decreased to an insufficient level.

Nowadays there are several biofungicides commercially available, and they are used in different ways. In this paper we describe some practical experiences of application methods for biofungicides developed by Verdera Oy. These products are based on the bacterium Streptomyces and the fungus Gliocladium catenulatum, and both are broad-spectrum bioagents that can be used on various crops.

Material and methods

Biofungicides and application methods
The Streptomyces K61-based biofungicide Mycostop® is registered and widely used in
Europe and North America. It is aimed at controlling several seed- and soil-borne pathogens, especially *Fusarium* wilt and damping-off on a range of edible and ornamental greenhouse crops. This formulation is suitable for seed treatment, drench, spray and drip irrigation. Mixing with the growing medium is also possible.

Other microbial fungicides of Verdera Oy are Prestop® and Prestop®Mix, both based on *G. catenulatum* strain J1446, which was approved at the EU level in 2005. Prestop® is registered also in North America. Both Prestop® formulations effectively control soil-borne pathogens like *Pythium* and *Rhizoctonia*. Besides root diseases, *G. catenulatum* is also effective against foliar diseases caused by *Didymella bryoniae* on cucumber and *Botrytis cinerea* on vegetables and ornamental plants. Of the two different formulations, Prestop® is suited for spraying and drip irrigation, while Prestop®Mix was developed mainly for incorporation treatment, although drenching is also possible. Both formulations can be used for inhibiting diseases in the root zone, whereas Prestop® as a sprayable formulation is suitable for controlling foliar diseases as well.

**Diseases and crop plants**

In this paper, we give examples of the main target diseases, namely damping-off, root rot, wilt and foliar diseases. In the case of damping-off, *Alternaria* and *Pythium* were chosen as test organisms. The application of Mycostop® was studied in *Brassica* seedling production where *Alternaria brassicicola* was the causal agent of damping-off. The application methods of Prestop® formulations were evaluated for their usability in controlling *Pythium* infection on seedlings of cucumber, lettuce and basil. *Pythium* root diseases, occurring at later stages of plant growth, were chosen as test objects on cucumber and tomato in rockwool cultivation and on pot plants in peat-based mixes. Mycostop® was widely tested also on carnation and gerbera, which are very susceptible to *Fusarium oxysporum* wilt.

The efficacy of the antagonist *G. catenulatum* (Prestop®) was evaluated against two foliar pathogens: *D. bryoniae* on cucumber and *B. cinerea* on tomato. These pathogens were chosen as target organisms because they can be controlled by sprayings directed to the site of infection.

**Results and discussion**

**Damping-off**

Mycostop® dry seed treatment has turned out to be an excellent method for the control of a range of seed-borne pathogens causing damping-off such as *Alternaria*, one of the most common seed pathogens on many vegetables and ornamental plants. In most cases the effect is similar to that of chemical fungicides, sometimes even better. Also seed soaking proved to be successful in a study by Mohammadi and Lahdenperä (1994). Soaking of seeds in an aqueous Mycostop® suspension controlled *Rhizoctonia solani* damping-off on cauliflower more effectively than incorporation or spraying application. In practice, however, soaking is an inconvenient way to treat as small seeds as many horticultural crops have.

When Mycostop® is applied by seed treatment, the microorganism immediately colonises the emerging root and begins to grow in the rhizosphere zone, where it is able to utilize root exudates and sloughed root cells. In spite of this effective establishment on the target site, Mycostop® dry seed treatment is not very common in practice for several reasons, one being the hygroscopic nature of the powder, which may cause technical problems in mechanised sowing. Another reason is that seeds are often treated with a chemical fungicide by the seed company, which may result in incompatibility between the biological and the chemical products.
Instead of treating seeds, it is often more practical and easier for the grower to treat the growing medium. Incorporation is in most cases a better method also with respect to the efficacy, especially when soil-borne pathogens are involved. Prestop®Mix has proved to be particularly effective as an incorporation treatment in controlling *Pythium* and *Rhizoctonia* damping-off in Verdera Oy’s own trials as well as in commercial cultivations. Also Mycostop® gave a disease control efficacy of 50% against *Fusarium oxysporum* infection on basil at an extremely high infection level in Italy when the product was incorporated into the growing medium before sowing (Gullino, 2002, unpublished). Similar control efficacy was achieved against *Pythium ultimum*, too.

Depending on the peat treatment and sowing system, use of Prestop®Mix powder as such may sometimes be the most practical way of application. However, from the efficacy point of view, the most recommendable method is to add the product as an aqueous suspension, which enables the *Gliocladium* propagules in Prestop®Mix to quickly become activated. Further, it is also easier to mix the product evenly into the growing medium as an aqueous suspension than as a powder.

As an alternative to incorporation, a drench treatment can be performed after sowing. In a study carried out by Punja and Yip (2003), Prestop®Mix and Mycostop® reduced in one trial *Pythium aphanidermatum* damping-off on cucumber by 49% and 78%, respectively and in a second trial by 52% and 100%, respectively. It is worth noting that these results were achieved under a very high disease pressure: in both trials the seedling mortality due to *Pythium* infection was approximately 70%. Also in our own seedling production trials, a Prestop® drench immediately after sowing gave nearly 90% efficacy against extremely strong *Pythium* infection.

**Root and wilt diseases**

Originally, Mycostop® was mainly applied by spraying the growing medium for the control of root rot and wilt disease. In addition, roots of cuttings could be dipped in a Mycostop® suspension. There are numerous examples of successful control of *F. oxysporum* wilt by Mycostop® in carnation and gerbera in commercial greenhouses in Finland, Holland and Canada. Mycostop® spray treatments resulted in higher yields and better plant quality. The product provided especially good protection against carnation wilt when root dipping of cuttings was combined with repeated soil sprayings (Lahdenperä, 1987). A disease control efficacy of 79% was achieved in a commercial, naturally infected cultivation when Mycostop was sprayed monthly at the rate of 10 g/100 m², combined with the dipping treatment (Lahdenperä, 1987). In another carnation trial, Mycostop reduced the disease incidence by 100% and thus increased the yield by 60%.

Spray treatment of the growing medium has turned out to be a very effective way of controlling root and stem base diseases on several crops, and this application method is included in the product label of both Mycostop® and Prestop®. However, in larger areas in commercial greenhouse cultivation it is more practical to deliver the biological fungicides via drip irrigation. At least in the case of Mycostop®, application through the drip irrigation system is nowadays the preferred way of using the product. It is a labour-saving application method, and thereby gives great benefit to the grower. Besides, applied via the drip irrigation, all of the product ends up precisely in the plant rhizosphere where it is targeted. The uniform delivery of Mycostop® through drips was initially tested in a large gerbera cultivation in Holland. In practice, the microbial suspension has to be added to the irrigation water either via an injection pump, or alternatively it can be poured into a mixing tank.

As Mason (2007) mentioned, incorporation of biofungicides into the growing medium in advance, either as a dry granular formulation or as a liquid drench, is an important application...
method for the control of root diseases. This is due to the preventive character of biological fungicides, which means that antagonists work best when they are present prior to the establishment of the pathogens. Particularly lettuce and pot plant growers find it very convenient that the growing medium can be treated with a microbial fungicide before sowing or transplanting. Verdera’s Prestop® Mix is such a product which is well suited for mixing with the growing medium in advance to inhibit root diseases. If there is a need to amend peat with a biofungicide long before use, Prestop® Mix can well be applied, since the *G. catenulatum* propagules in the product survive in an organic medium for several weeks.

*Pythium* fungi may stay latent in seedlings and cause symptoms on certain crops later in the growing season. Such a crop is tomato, especially when grown in rockwool. *Pythium* often appears on tomato in the middle of the summer, suppressing growth although the plants otherwise look healthy. In Finland tomato growers avoid this kind of retarded growth by applying Mycostop® through the drips at regular intervals during cropping.

Soil-borne diseases are difficult to control even with chemical fungicides, so integrated control is often needed to improve the efficacy. Combining a fungal antagonist with chemicals is not always easy, whereas the bacterial biocontrol agent Mycostop is extremely well suited for integrated disease control.

**Foliar diseases**

Spraying a cucumber crop with Prestop® in order to control gummy stem blight infection (*D. bryoniae*) is common practice in many commercial cultivations (Niemi & Lahdenperä, 2000). Although the pathogen can infect also the upper parts of the canopy, particularly the flowers, sufficient efficacy is achieved by spraying the stem bases after planting and repeating the treatment once or twice.

Biological grey mould control using Prestop® was first tested in seedling production, where it is easy to drench or spray the whole foliage. Later in the season, it is possible to use Prestop® e.g. on tomato by spraying directly on the disease lesions. The targeted treatment can be done using a small hand-sprayer, which is easy to carry along when tending the crop. Although biological disease control usually has to be started before the pathogen attacks, trials and practical experience have shown that *G. catenulatum* is able to stop further development of *Didymella* and *Botrytis* infection even in situations where symptoms already occur. The reason for this is that the pathogens do not immediately damage the whole plant stem, but initially cause only one-sided lesions, thereby allowing the biocontrol agent time to exert its antagonistic activity.

**References**


Prospects for biological control of pest problems in outdoor nursery production in Western Canada

Mario Lanthier
CropHealth Advising & Research, P.O. Box 28098, Kelowna British Columbia, Canada, E-mail: office@crophealth.com

Abstract: Because of a variety of climates and surrounding vegetation, the nature of pest problems and requirements for seasonal monitoring change from nursery to nursery within Canada. Preservation of naturally-occurring biocontrol agents is currently difficult because of pesticide control for various insect pests. On-going registration of low impact and microbial pesticides will allow the development of new management programs and increased reliance on biological control.

Key words: Canada, pest problems, seasonal monitoring, biological control

Introduction

In Canada, commercial nurseries are found in all regions that offer suitable climate and land. In 2006, production covered 22,556 hectares and generated 7,600 full-time and 6,500 part-time employees (Statistics Canada, 2007). Total sales were Can$595.2 million, mostly to landscape contractors (28.2%) and garden centres (23.3%). Largest production areas were Ontario (47.7% of sales), British Columbia (28.2%) and Québec (11.8%).

Impact of regional conditions

Nurseries located at the B.C. Coast
This region is characterized by some of the mildest climates in Canada, resulting in a large concentration of nurseries (British Columbia Ministry of Agriculture, 2006). Weather conditions are typically 20 to 30°C with periods of rain during the summer and near 0°C with extensive rain during the winter. Damaging pest problems are the black vine root weevil (*Otiorhynchus sulcatus*), the two-spotted spider mites (*Oligonychus urticae*), bacterial canker (*Pseudomonas syringae*), root rot (especially *Phytophthora* spp.) and the weed liverwort (*Marchantia polymorpha*).

Nurseries located in the B.C. Interior
This region is characterized by minimal overwintering requirements, a long growing season, and availability of good quality water (British Columbia Ministry of Agriculture, 2003). Weather conditions are typically 25 to 35°C with minimal precipitation during the summer and below 0°C with occasional rain or snow during the winter. Damaging pests are bronze birch borers (*Agrilus anxius*) and aphids (various species), and the diseases fire blight (*Erwinia amylovora*) and powdery mildew (various species).

Nurseries located in Southern Alberta
Weather conditions are typically 25 to 35°C with minimal precipitation during the summer and prolonged periods at -10 to -20°C with occasional snow during the winter. Damaging pest
problems are insect borers such as bronze birch borer (*Agrilus anxius*) and poplar-and-willow borer (*Cryptorhynchus lapathi*), and the diseases fire blight (*Erwinia amylovora*) and aspen shoot blight (*Venturia* species).

**Seasonality of insect pests**
In British Columbia, monitoring records indicate insect pest problems are most prevalent in late spring and early summer (Table 1). Nursery growers are advised to conduct a minimum of 10 monitoring visits each season, especially from May to August, and increase to 18 visits when growing coniferous stock (British Columbia Ministry of Agriculture, 2002).

Table 1. Seasonal occurrence of insect pests, based on type of plant damage, for the Southern B.C. Interior, data from 1992 to 2002 (modified from CropHealth Advising & Research, 2002).

<table>
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<tr>
<th>Month</th>
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<th>Chewing</th>
<th>Gall Forming</th>
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<td>7</td>
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</table>

**Programs for biological control**

**Biocontrol of insects**
The green peach aphid (*Myzus persicae*) is a pest of ornamental plants worldwide (Blackman & Eastop, 2000). Native beneficials found in British Columbia nurseries include aphid midges (*Aphidoletes* spp.), parasitic wasps (Braconids, Chalcidids and Ichneumonids) and syrphid flies (*Syrphidae* spp.) (Lanthier & Jensen, 2002). The black vine weevil (*Otiorhynchus sulcatus*) and other root weevil species are common across North America. Biocontrol with entomopathogenic nematodes (such as *Steinernema carpocapsae*) is effective in container production but less effective in field production, likely because of soil temperatures and structure (Booth et al., 2002). The coming registration of the entomopathogenic fungi *Metarhizium anisopliae* should improve control (Bruck & Donahue, 2007). The two-spotted spider mite (*Oligonychus urticae*) is a pest of ornamental plants worldwide (Helle & Sabelis, 1985). The increased use of insecticides in the chloronicotinyl family, such as imidaclopid and acetamiprid, has resulted in increased spider mite outbreaks (James & Price, 2002).

Field research was conducted at an outdoor nursery in 1999. Commercially-available predatory mites were released in container grown *Potentilla fruticosa*. The impact was minimal as naturally occurring predators (especially the minute pirate bugs *Orius* spp.) were present in control plants to feed on aphids and thrips (Custer & Lanthier, 1999). Starting in 2000, the grower discontinued the use of acephate, a broad spectrum pesticide. The preservation of the naturally occurring spider mite predators has eliminated the need for miticide sprays.

The spruce spider mite (*Oligonychus ununguis*) is an important pest of conifers in North America (Johnson & Lyon, 1991). There are sporadic reports of biological control (Wheeler et al., 1973).

Field research was conducted at an outdoor nursery in 1994 and 1995. Commercially-
available predatory mites were released in container-grown Thuja. There was no measurable impact. Field populations of the spruce spider mite are likely controlled by weather conditions, especially ambient temperatures and rainfall (Lanthier, 1997).

**Biocontrol of weeds**

In British Columbia, biocontrol of weeds is currently limited to plants of range land such as spotted knapweed (*Centaurea maculosa*) (Powell *et al*., 1994). There is currently no effective biocontrol agent for common nursery weeds. A new herbicide based on the fungus *Sclerotinia minor* offers 80% control of dandelion (*Taraxacum* spp.) when applied post-emergence (Pest Management Regulatory Agency, 2007).

**Biocontrol of diseases**

Fire blight (*Erwinia amylovora*) is a pest of Rosaceae plants world-wide (van der Zwet & Beer, 1991). Fungicides based on competitive strains of the naturally-occurring bacteria *Pantoea agglomerans* are now available (Pest Management Regulatory Agency, 2006). They are most effective when used in combination with traditional control methods (Momol *et al*., 1999). Root rot (especially *Phytophthora* spp.) is found on ornamental plants world-wide (Erwin & Ribeiro, 1996). Competition with native biocontrol agents is obtained in soils containing high quality organic matter or amended with cured compost (Stone *et al*., 2004). Recent research indicates that biocontrol-fortified potting mixes can trigger Induced Systemic Resistance and help prevent leaf diseases caused by *Botrytis* and powdery mildew (Horst *et al*., 2005).

**Conclusion**

Pest management in outdoor nursery production is different from protected cultures. In greenhouse production, environmental and growing conditions are standardised for optimum plant growth. The result is a set of pest problems relatively constant around the world that includes aphids, whiteflies, two-spotted spider mites and thrips (Heinz *et al*., 2004). In outdoor nursery production, there is little control over environmental and growing conditions. The result is a complex of pest problems that varies from site to site. There is a need for more research in conservation of naturally occurring biocontrol agents in outdoor nursery production. One current roadblock is the control of tree borers with broad-spectrum high toxicity pesticides such as chlorpyrifos, dimethoate and endosulfan (Ontario Ministry of Agriculture, 2007). Introduction of new methods such as mating disruption (Welter *et al*., 2005) and tree injection (Doccola *et al*., 2007) will help preserve natural biocontrol.

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Status of Integrated Pest Management (IPM) practices in outdoor nursery production in Canada

Mario Lanthier¹, Peter Isaacson²
¹CropHealth Advising & Research, P.O. Box 28098, Kelowna, British Columbia, Canada; ²Canadian Nursery Landscape Association, 7856 Fifth Line South, Milton, Ontario, Canada

Abstract: Surveys were conducted in 2002 in British Columbia and in 2004 across Canada to assess use of IPM practices by commercial nursery growers. Results indicated widespread knowledge of IPM concepts and regular use of crop monitoring and biologically-based pesticides. A second survey conducted at the same time measured the use of pesticides in outdoor nurseries. Results indicated common use of broad-spectrum insecticides such as organo-phosphates and organo-chlorines. These products are detrimental to naturally-occurring insect predators and parasites. Increased use of IPM practices may result from nursery certification programs being implemented to ensure plants are shipped relatively free of pest problems.

Key words: Canada, IPM, grower survey, monitoring, pesticide use, nursery certification

Introduction

Integrated Pest Management (IPM) has been practiced in outdoor nurseries for many years. In the United States, a report published in 1988 described IPM practices in nurseries in the state of Maryland (Raupp & Cornell, 1988). The comments triggered a 1992 training manual by the Bio-Integral Resource Center (Darr et al., 1992). More recently, a 422-page book on IPM for nurseries was published by the University of California (Dreistadt, 2001). Use of IPM in Canadian nurseries also has a long history. In a 1995 directory of IPM practitioners, 491 persons were listed, of which 57 indicated working in nursery IPM, either as government extension agent, university researcher or crop consultant (Lanthier et al., 1995).

Current use of IPM

Government publications

Government agencies encourage the use of IPM practices in commercial nursery production. In Ontario, a 136-page publication for nursery growers contains 4 pages specifically on IPM, including qualifications for crop scouts and suggested monitoring tools (Ontario Ministry of Agriculture and Food, 2007). In Quebec, personal interviews were conducted in 2005 with 12 nursery growers to verify the adoption of specific IPM practices. Growers scored highest on recognition of early damage by aphids and spider mites, adequate pruning for fire blight and juniper Phomopsis blight, but scored lowest for use of nematodes against root weevil, spray timing based on trap catches for peach tree borer and use of mulches for weed control in container production (pest species not specified) (Martineau & Tousignant, 2006). In British Columbia, a 307-page publication for nursery growers contains 27 pages specifically on IPM. One section offers a step-by-step approach to build a nursery IPM program (Lanthier & Jensen, 2002). Crop monitoring must be done by a person dedicated to the task and not
expected to perform other duties such as shipping or pruning during the inspection. A nursery crop monitor must recognize normal from abnormal plant growth, as many problems first appear on the newest foliage; must use a variety of methods such as sticky traps and indicator plants for insect pests and seasonal weather conditions for diseases; and should seek the observations of department supervisors. Time allocation varies with the season and the number of crops. Monitoring can be done over one day every second week for some nurseries, but requires two days per week for other nurseries. During spring and summer, when pest problems are more numerous, each production area should be inspected at least once per month.

Research in IPM practices

In 2003, the Canadian Nursery Landscape Association hired a “National IPM/Minor Use Coordinator” to coordinate national IPM projects and manage registrations of new pesticides (Canadian Nursery Landscape Association, 2007). Fourteen projects were funded from 2003 to 2007. Examples include biological control of root weevil (various species), management of cottony psyllid (Psyllipsis discrepans), and development of an IPM program for rose midge (Dasynerua rhodophaga). One project examined the use of mulches and disks for weed control in container production. Results indicated a 95 to 98% weed reduction over one year with woven coco-fiber disk, moulded plastic lid disk and crumb rubber mulch. The mulches and disks are now used in commercial container production, especially in regions receiving extensive rainfall where weed growth is rapid at the base of slow-growing plants such as boxwood (Buxus), oak (Quercus) and spruce (Picea) (Lanthier et al., 2006).

Surveys of IPM use

Survey in British Columbia

In 2002, the provincial nursery association arranged the distribution of two surveys to wholesale nurseries. The overall objective was to establish baseline data. The first survey determined the use of IPM practices, based on voluntary answers from 51 growers producing on 1,447 hectares, representing 34.4% of total nursery land production (Zbeetnoff, 2003a). Thirty-seven growers (74% of the total) answered they practice IPM, defined as “a dynamic decision-making process that emphasizes the use of non-chemical management techniques to prevent or manage pest problems”. Results indicated a high proportion of growers (over 80%) used “a formal process” to detect weeds, insects and diseases in the production areas (Table 1). Fewer growers (30 to 35%) monitored insects and diseases in perimeter areas. Monitoring for insect pests was done in field production mostly by the operator or a family member (16 of 29 respondents), whereas in container production it was done mostly by an employee (20 of 45 respondents). The second survey measured the use of pesticides for the 2002 calendar year. Results were based on voluntary answers from 53 growers producing on 1,863 hectares, representing 61.2% of total land production (Zbeetnoff, 2003b). Growers reported using 159 pesticide products representing 99 active ingredients (a.i.). The most common insecticide/miticide was dormant oil, accounting for 78.3% of total active ingredient amount (Table 2). Growers reported using many broad-spectrum pesticides such as dimethoate, endosulfan and carbaryl. These products can disrupt naturally-occurring insect predators and parasites (British Columbia Ministry of Agriculture, 2002). The Canadian government recently announced deregistration of endosulfan (Pest Management Regulatory Agency, 2007).

Survey across Canada

In 2004, a survey of IPM practices was distributed to wholesale nurseries across the country,
similar in scope and content to the British Columbia (B.C.) survey of 2002 (Zbeetnoff, 2005). Final results of the B.C. and Canada-wide surveys are based on voluntary answers from 107 growers producing on 4,856 hectares, representing 21.3% of total nursery land production.

Table 1. Percent of total respondents (51) using “a formal process” to detect pests at their commercial outdoor nursery in British Columbia.

<table>
<thead>
<tr>
<th>Pest type</th>
<th>Field production</th>
<th>Container production</th>
<th>Propagation</th>
<th>Yard, perimeters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weeds</td>
<td>93.3</td>
<td>89.4</td>
<td>82.3</td>
<td>85.0</td>
</tr>
<tr>
<td>Insects, mites</td>
<td>90.0</td>
<td>87.3</td>
<td>91.2</td>
<td>35.0</td>
</tr>
<tr>
<td>Diseases</td>
<td>80.0</td>
<td>85.1</td>
<td>88.2</td>
<td>30.0</td>
</tr>
<tr>
<td>Wildlife</td>
<td>56.7</td>
<td>57.4</td>
<td>35.3</td>
<td>32.5</td>
</tr>
</tbody>
</table>

Table 2. Insecticide/miticide use by chemical class for 2002 in British Columbia nurseries.

<table>
<thead>
<tr>
<th>Chemical class</th>
<th>Example of product</th>
<th>kg of a.i.</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>dormant oil</td>
<td>4,112,193</td>
<td>78.3</td>
</tr>
<tr>
<td>Organo-phosphate</td>
<td>acephate, dimethoate</td>
<td>660,219</td>
<td>12.6</td>
</tr>
<tr>
<td>Organo-chlorine</td>
<td>dicofof, endosulfan</td>
<td>246,218</td>
<td>4.7</td>
</tr>
<tr>
<td>Carbamate</td>
<td>pirimicarb, carbaryl</td>
<td>95,303</td>
<td>1.8</td>
</tr>
<tr>
<td>Fatty acid</td>
<td>insecticidal soap</td>
<td>70,056</td>
<td>1.3</td>
</tr>
<tr>
<td>Pyrethrin</td>
<td>permethrin, deltamethrin</td>
<td>36,298</td>
<td>0.7</td>
</tr>
<tr>
<td>Organotin</td>
<td>fenbutoxin-oxide</td>
<td>15,350</td>
<td>0.3</td>
</tr>
<tr>
<td>Chlorinated hydrocarbon</td>
<td>pyridaben</td>
<td>7,980</td>
<td>0.15</td>
</tr>
<tr>
<td>Other</td>
<td>spinosad, abamectin</td>
<td>2,956</td>
<td>0.06</td>
</tr>
<tr>
<td>Chloronicotinyl</td>
<td>imidacloprid</td>
<td>1,449</td>
<td>0.03</td>
</tr>
<tr>
<td>Insect growth regulator</td>
<td>kinoprene, cyromazine</td>
<td>1,021</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Table 3. Practices rated as “very important” by growers wishing to improve their IPM program.

<table>
<thead>
<tr>
<th>Practice suggested</th>
<th>B.C.</th>
<th>Prairies</th>
<th>Ontario</th>
<th>Québec</th>
<th>Atlantic</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge of beneficials</td>
<td>17</td>
<td>9</td>
<td>15</td>
<td>3</td>
<td>3</td>
<td>47</td>
</tr>
<tr>
<td>Available low risk products</td>
<td>19</td>
<td>7</td>
<td>13</td>
<td>4</td>
<td>3</td>
<td>46</td>
</tr>
<tr>
<td>Increased training about IPM</td>
<td>17</td>
<td>9</td>
<td>12</td>
<td>1</td>
<td>3</td>
<td>42</td>
</tr>
<tr>
<td>Wider range of chemicals</td>
<td>14</td>
<td>6</td>
<td>14</td>
<td>4</td>
<td>3</td>
<td>41</td>
</tr>
<tr>
<td>Knowledge of pest thresholds</td>
<td>12</td>
<td>6</td>
<td>10</td>
<td>2</td>
<td>3</td>
<td>33</td>
</tr>
<tr>
<td>Information on banker plants</td>
<td>9</td>
<td>6</td>
<td>9</td>
<td>2</td>
<td>2</td>
<td>28</td>
</tr>
<tr>
<td>Established economic benefits</td>
<td>11</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>27</td>
</tr>
<tr>
<td>Reasonably priced products</td>
<td>7</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td># of growers answering</td>
<td>26</td>
<td>10</td>
<td>22</td>
<td>5</td>
<td>5</td>
<td>68</td>
</tr>
</tbody>
</table>
Future prospects

Nursery certification programs are being introduced across Canada with the general aim to sell plants “relatively free of pest problems”. A secondary impact will be the hiring of persons with skills typical of IPM, such as monitoring and diagnosis of pest problems. These programs include *P. ramorum* certification in British Columbia, the Canadian Nursery Certification Program for export to the United States (Canadian Food Inspection Agency, 2006), and the Domestic Phytosanitary Certification Program for domestic plant movement (Canadian Nursery Certification Institute, 2007).

References


Canadian Nursery Certification Institute, 2007: www.cleanplants.ca/.


IPM strategies in the Colombian cut flower industry

Rebecca A. Lee
Colombian Centre for Innovation in Floriculture (Ceniflores), Cra 9 A, No.90-53, Bogotá, Colombia, E-mail: rebeccal@asocolflores.org

Abstract: Colombia is second world exporter of flowers after Holland. Flowers are the second most important agricultural export industry of the country. The Colombian Flower Exporters’ Association (Asocolflores), through the Colombian Centre for Innovation in Floriculture (Ceniflores), provides leadership in the industry by implementing programmes that help maintain its competitiveness. Among these programmes is Florverde®, a management tool to help flower growers work toward socially and environmentally sustainable development, an agreement with the national plant protection organism for the coordination of plant health campaigns, and research projects in IPM coordinated by Ceniflores.

Key words: Colombia, integrated management, cut flowers, national programmes

Introduction: The importance of Colombian floriculture

Colombia is second world exporter of flowers after Holland. Flowers are the second most important agricultural export industry of the country. About 80% of exports go to the United States, making Colombia the first supplier of flowers into that country: 6 out of 10 flowers sold in the US come from Colombia, and for some species such as alstroemeria, chrysanthemum and carnation, Colombian participation in the US exceeds 90%. About 9% of exports go to the European Union.

Cut ornamentals for export are currently cultivated in over 7,000 hectares, mostly in greenhouses; of these, 75% are in the Bogotá area (2,600 m altitude), 20% in the Rionegro valley of Antioquia (2,200 m) and the rest in the Cauca valley and coffee growing areas (1,200 to 1,600 m). Three quarters of the area consist of three flower species, rose, carnation and chrysanthemum, but close to 50 species of flowers and some foliage are grown, especially to provide for the increasing bouquet market.

Colombian flower exports represent about US$1 billion, with an average of 25 to 30 flights daily. It is an important source of employment in a country fraught with many social problems: the sector provides 200,000 direct and indirect jobs and over a million people depend on the sector for their livelihood.

Plant health as well as social and environmental requirements of the various importing countries are becoming constantly more demanding, especially within the context of new free trade agreements. For the export of cut flowers, these demands translate into increased financial, logistical and technological investments that can become quite complicated. The Colombian Flower Exporters’ Association (Asocolflores), through the Colombian Centre for Innovation in Floriculture (Ceniflores), provides leadership in the industry in the search for solutions through plant health campaigns as well as support for research in related areas.
Florverde®: the Colombian flower sector’s answer to social and environmental requirements

In 1996, Asocolflores created Florverde® as a management tool to help flower growers work toward sustainable development. They defined sustainable development as “social responsibility and environmentally friendly production, coupled with productivity and profitability”. The program is based on cleaner production (less water, less energy and fewer toxic inputs), continuous improvement, measuring, recording and benchmarking (comparing themselves to other farms in the program). The principles behind Good Agricultural Practices, as well as ISO 14000 and other international agreements, are the basis for this program.

From 1996 to 2007, the numbers of participating farms went from 28 pilot farms to 140 companies, of the total 226 members of Asocolflores. Results include the development of personal and family growth programmes, strict compliance of labour legislation and conditions, improved occupational health management, recycling of residues, use of fertilisers and organic amendments on the basis of soil analyses, soil preparation and irrigation according to soil properties, use of rain water for irrigation. Where pest management is concerned, results include no use of methyl bromide since 1995 and a 46% reduction in the amount of active ingredient used per farm between 1998 and 2006 particularly of products of categories 1 A and 1 B, through emphasis on monitoring, pest prevention, use of insect vacuums, and of biological and botanical control. The process is implemented through training and monitoring of the farms by a specialist group on all aspects of the program, institutional strengthening of Asocolflores, and recognition nationally and internationally of the quality of the program. By the end of 2007, 86 companies had been certified by SGS, the Swiss-based company. Asocolflores is currently member of the industry committee for Fair Flowers and Plants, Florverde® cumplies with the Ethical Trade Initiative code and expects to complete benchmarking with GlobalGAP by early February.

IPM strategies through Ceniflores

ICA-Asocolflores agreement for plant health campaigns
This agreement was subscribed in 1990 between Asocolflores and ICA (Colombian Agricultural Institute, the national organization for plant and animal protection) to look for solutions in order to avoid trade barriers due to the appearance in Colombia of chrysanthemum white rust, *Puccinia horiana* (CWR). A protocol for farm management of the pest with a surveillance and control system was developed. In 1998 and again in 2007, this protocol was approved by the US Aphis. In 1998, the agreement was extended to include other quarantine pests. Over time, a close relationship has been developed with national plant health organizations of the different importing countries, especially Aphis, which collaborates closely in the Colombian mitigation efforts by providing data on pest interceptions in Miami.

Implementation of the agreement
Both parties provide personnel to cover administrative, field and laboratory activities, which are coordinated though operation committees and links to the growers through committees on plant health trade barriers. Estimated costs to Asocolflores and the growers exceed US$ 4 million a year in the case of CWR and double that amount for all other quarantine pests. All farms registered for export (over 1,200) are visited at least once a year to verify compliance with export protocols. ICA maintains a database with GPS location, plant health history and general information for each farm. Growers are continuously educated on up-to-date national and international requirements. When research is required, this is coordinated with Ceniflores.
Results of the plant health campaigns

These include: growers with up-to-date information on plant health requirements for export, continuous monitoring by the farms and the members of the agreement, fluid communication between the flower sector and the national plant health organization, Antioquia free of CWR, control of CWR in the Bogotá area, recognition by Aphis of the Colombian CWR protocol, fast release programme in Miami for reduced risk flower species, extension manuals and DVDs on quarantine pests for on-farm training.

Research and development

Ceniflores is a research centre based on a “virtual” design: it coordinates the prioritized demand for research and extension of the growers with universities or research centres that supply the answers. This allows for flexibility in the use of researchers with the know-how to solve the sector’s problems, reduces competition for scarce resources, and helps strengthen the research team by acquiring personnel and equipment through funding acquisition. Research requirements are organized through programmes (IPM, soils and substrates, integrated crop production, etc.) so as to create long-term relationships of mutual benefit.

Within the IPM programme, past projects have included biological control of *Tetranynchus urticae* in roses, IPM strategies in rose crops with special emphasis on biological control, and identification of Noctuidae in cut flowers, in particular of *Copitarisia* sp. Current projects include the construction of a reference collection and interactive DVD for identification of arthropods associated with Colombian cut flowers, downy mildew research including the effect of plant nutrition on disease incidence as well as climate management and epidemiology of the pathogen under different greenhouse structures, efficacy trials for chemical, botanical and biological control of *Botrytis* and *Copitarisia* sp., monitoring of deleterious and beneficial bacteria after steam sterilization of soils, and work on entomopathogenic fungi and botanical products for the control of *Scutigerella* sp., and *Tetranynchus urticae*.

Of special note is the project, “Advancing the Adoption of Pest Management Strategies on Cut Flowers Produced in the United States and Colombia”, which is a joint effort between two universities in the US (UC Davis and Texas A&M), two universities in Colombia (Jorge Tadeo Lozano and Nueva Granada), Ceniflores and three suppliers of biorational products (Koppert for arthropods, Ecoflora for botanicals, LST for entomopathogenic fungi). This is a three-year project with funding from the American Floral Endowment and the Colombian Ministry of Agriculture.

Conclusions

The Colombian flower industry has pushed for the rational use of pesticides and the search for ecological alternatives formally for over 10 years. Within the international context, it is an important partner not only for research but also for the mitigation of quarantine pests. The Florverde® programme is an example to be followed on how to implement environmentally sound practices in a large sector, as is the strong long-term relationship built up between Asocolflores and the Colombian national plant protection organization, ICA.

Integrating the different pest management strategies on the farms remains a challenge which the joint research project described above should help to solve. Other challenges which are common to many Latin American countries include mass production of arthropod biological control agents and the ability to develop useful results quickly for the management of new pests.
References

www.asocolflores.org
www.ceniflores.org
Can natural flightless ladybird beetles improve biocontrol of aphids?

Suzanne T.E. Lommen¹, Cock W. Middendorp², Carola A. Luijten¹, Jeroen van Schelt³, Paul M. Brakefield¹, Peter W. de Jong²

¹Institute of Biology, Leiden University, P.O. Box 9516, 2300 RA Leiden, The Netherlands, E-mail: s.t.e.lommen@biology.leidenuniv.nl; ²Laboratory of Entomology, Wageningen University, P.O. Box 8031, 6700 EH Wageningen, The Netherlands; ³Koppert B.V., P.O. Box 155, 2650 AD Berkel en Rodenrijs, The Netherlands

Abstract: We investigated the effect of releasing flightless morphs of the ladybird beetle Adalia bipunctata onto single, caged pepper plants that were infested by aphids of Myzus persicae nicotianae or Aulacorthum solani. Overall, plants with flightless ladybird beetles showed lower aphid numbers after 48 hours than those receiving either winged or no beetles. These results were best explained by a longer residence time of the flightless beetles on the host plant. The benefit of using flightless beetles over winged ones was greatest for M. persicae, most likely because this species of aphid, in contrast to A. solani, does not drop off the plant as an escape response to the presence of beetles.

Key words: flightless Adalia bipunctata, aphid pests, consumption, escape response, ladybird beetle

Introduction

The main problem of using ladybird beetles for biological control of aphid infestations is the tendency of adults to fly away from the crop soon after release (Obrycki & Kring, 1998). Though the release of juvenile stages delays dispersion, the use of flightless beetles can in theory prolong residence time even more and might, therefore, improve biocontrol of aphids.

Ignoffo et al. (1977) de-winged Hippodamia convergens manually and Ferran et al. (1998) obtained a flightless morph of Harmonia axyridis by mutagenesis and artificial selection. In contrast to such artificial techniques to create flightless beetles, it could be beneficial to utilize natural morphological variation, such as occurs in the two-spot ladybird beetle, Adalia bipunctata. Flightless morphs of this species that lack the distal part of both pairs of wings are regularly encountered in the wild. Since the trait is controlled genetically (Marples et al., 1993) one can easily rear populations from field collected flightless individuals.

We compared, for the first time, the ability of flightless A. bipunctata to reduce aphid pests to that of their winged conspecifics using single, caged pepper plants and two species of aphid. In addition, we tested the consumption of these aphids and an additional species by the two morphs of the beetle in a Petri dish experiment.

Material and methods

Aphids

For the cage experiment, we used two species that are well known pests in greenhouses: Aulacorthum solani and Myzus persicae nicotianae. They were kept on leaves of sweet pepper (Capsicum annuum cv. Lesley) that were maintained on 1% agar solutions in Petri dishes (75 mm Ø × 30 mm) covered with a mesh net at a temperature of 23.5 (±1)ºC at a 16L:8D light
regime. For the consumption experiment we also used *Rhodobium porosum* reared in the same way on strawberry leaves (*Fragaria x ananassa*, cv. Elsanta).

**Ladybird beetles**

Laboratory populations of *A. bipunctata* that had been established between 2000 and 2005 provided flightless (-/- for the trait) and winged ladybird beetles (+/- or +/-). Larvae were fed with *Ephesia kuehniella* eggs ad lib and kept at a temperature of 20.5 (±1)°C and a 16L:8D light regime. For the cage experiment, eclosing adults were individually transferred to Petri dishes (75 mm Ø × 30 mm) containing pepper leaves, where they were allowed to feed ad lib from the aphid species that would be used in the experiment itself. They were kept at a temperature of 23.5 (±1)°C at a 16L:8D light regime. Only virgin females of age 2 to 17 days and an approximate body length of 6 mm were used. To minimise variation in the flightless phenotype, only beetles without any elytral tissue were used. For the consumption experiment, adults were kept on the *Ephesia* diet and only virgin females of age 8 to 12 days were used.

**Cage experiment**

We used single, caged aphid-infested pepper plants to test the effect of winged and flightless ladybird beetles on aphid populations and to monitor the location of the released beetles. Experiments were performed in nine cages (2.65 × 0.75 × 1.25 m) made of fine mesh net with a solid bottom in a greenhouse with minimum temperatures of 22.5°C and 21.5°C during the day and at night, respectively. A single pepper plant with a height of 65-80 cm was placed on the bottom of each cage such that it was not in contact with the cage. At least six leaves of each plant were infested with in total 15-50 aphids of one of the species. Aphids were allowed to settle and reproduce for one to three days and were then counted. The plants were then randomly allocated to one of three treatments: winged ladybird, flightless ladybird or control. In the ladybird treatments, a single winged or a flightless ladybird beetle was placed on top of the lowest leaf of the plant. During the next 48 hours, its location (on/off the plant) was monitored at 11 time points during daytime. It was then removed from the cage and the aphids remaining on the plants were counted. For *M. persicae*, each treatment was replicated 12 times, divided over six series of two replicates each. For *A. solani*, 10 replicates divided over four series of two or three replicates were obtained.

**Consumption experiment**

We compared the consumption of three species of aphid between winged and flightless ladybird beetles, using a Petri dish to minimise the effect of searching. We used dishes with pepper (randomly allocated to *A. solani* and *M. persicae*) or strawberry leaves (for *R. porosum*) as previously described under the same conditions. Aphids were allowed to settle in the dishes for one day, after which their number was reduced to 10 per dish. Dishes were then randomly allocated to one of three treatments (winged ladybird, flightless ladybird or control). In the ladybird treatments, a 24-hour starved ladybird beetle was introduced into the dish. Twenty-four hours later, all aphids were recounted. Each combination of treatment and aphid species was replicated 25 times, divided over two series.

**Statistical analysis**

To analyse the position of the ladybird beetles in the cage experiment we used a GLM with ladybird morph as factor and a binomial error distribution for each time point. When a beetle could not be detected, it was regarded as a missing value for that time point.

To analyse the effect of treatments on aphid numbers in the cage experiment, for each aphid species linear mixed effect models with a quasi-Poisson error distribution (fixed effects: treatment and number of aphids at time zero; random effect: series) were compared. One outlier in the control treatment of *A. solani* was excluded from the analysis.

The consumption experiment was analysed by a Kruskal-Wallis test followed by Mann-Whitney U tests for each aphid species. Analyses were performed in R 2.4.1 and SPSS 15.0.
Results and discussion

The consumption experiment showed that both ladybird beetles fed from all three species of aphids. (KW mean ranks for winged, flightless and control in M. persicae: 21.48, 30.36, 62.16; A. solani: 25.80, 27.08, 61.12; R. porosum: 24.86, 28.34, 60.80, respectively, all p<0.001). Winged beetles ate slightly more aphids than flightless beetles but this trend was only significant for M. persicae (MWU=212, p<0.05).

The cage experiment showed that winged beetles tend to leave the plants earlier than flightless beetles, and most of them do so within four hours after release (Figure 1). Only two hours after release, flightless ladybird beetles were significantly more often found to be on the plant than winged beetles (M. persicae: p<0.01; A. solani: p<0.05). This distribution persisted during the remainder of the experiment, except for plants with A. solani after 30 h (p=0.053). The latter can be explained by some winged ladybirds that returned to the plant with A. solani. Overall, these results corroborate earlier findings (Ignoffo et al., 1977; Ferran et al., 1998).

Figure 1. Location of winged (●) and flightless (○) beetles after release on single, caged plants infested with either M. persicae (left, N=8-12 plants) or A. solani (right, N=6-10).

The release of flightless ladybird beetles resulted in lower number of aphids on the plants (Figure 2). The effect of flightless ladybirds was significantly different from that of winged ladybirds (M. persicae: χ²=190.47; A. solani χ²=38.49: both p<0.001) and the control treatment (M. persicae: χ²=205.51; A. solani χ²=115.64; both p<0.001). This trend is similar in both aphid species but the difference with the winged ladybirds is largest in M. persicae. This is because, compared to the control at low initial aphid numbers, with winged beetles the numbers of M. persicae slightly increased (χ²=15.475, p<0.001), whereas the numbers of A. solani decreased (χ²=55.96, p<0.001) (Figure 2). The latter may be explained by the behaviour of A. solani, that is more likely to drop in the presence of A. bipunctata than is M. persicae (unpubl. results). Dropping behaviour is a well known escape response of aphids and is elicited by the presence of a predator or parasitoid (e.g. Losey and Denno (1998) and references therein). As ladybird beetles show negative geotropism and climb to the top of the plant to take off, winged ladybird beetles are likely to cause dropping behaviour before they leave the plant. Therefore, the effect of flightless ladybirds compared to that of winged ones may be stronger for species of aphid that do not drop.

To summarise, flightless ladybird beetles reduce the increase of aphid numbers more than their winged conspecifics, and this can be explained by longer residence times of flightless beetles on the plant, rather than by differences in feeding behaviour between the
morphs. However, none of the ladybird beetles was able to eradicate the aphid population on the plant. This is in line with Minoretti and Weisser (2000), who showed that individual *Coccinella septempunctata* were not able to remove all pea aphids on bean plants. Hence, whilst the release of flightless adults of *A. bipunctata* might improve biocontrol of aphids we predict it will not be sufficient to extinguish aphid populations. Additional experiments should reveal whether the same results can be obtained in larger, more realistic, settings.

Figure 2. The number of aphids on a pepper plant infested with *M. persicae* (left panel, N=36) or *A. solani* (right panel, N=30) 48 h after the release of winged (●) or flightless (○) ladybirds or the control treatment (⊤), plotted against the number of aphids prior to treatments. *outlier.

Acknowledgements

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References


Do whiteflies help controlling thrips?

Gerben Messelink1, Arne Janssen2
1Wageningen UR Greenhouse Horticulture, PO Box 20, 2265 ZG Bleiswijk, The Netherlands, E-mail: gerben.messelink@wur.nl; 2IBED, Section Population Biology, University of Amsterdam, PO Box 94084, 1090 GB Amsterdam, The Netherlands

Abstract: Studies on pest species diversity suggest that pests can enhance each other’s control through a shared generalist predator. This hypothesis was tested for control of western flower thrips by releasing greenhouse whiteflies in the presence of the shared predator *Amblyseius swirskii* on greenhouse cucumber. Predator densities strongly increased in the presence of both pest species, up to a tenfold compared to a situation with thrips only. However, this better performance of *A. swirskii* did not result in better control of thrips. Rather, thrips control was significantly delayed when whiteflies were present. We attribute this phenomenon to predator satiation caused by strong synchronisation of the pest populations after releasing high numbers of adults at once. It is suggested that repeated releases of lower numbers of whiteflies may improve biological thrips control.

Key words: biological control, *Amblyseius swirskii*, *Frankliniella occidentalis*, *Trialeurodes vaporariorum*, apparent competition, apparent mutualism, food web interactions, biodiversity

Introduction

The use of generalist predators for biological control has become more widespread in the last years and the interest for generalist predatory mites is increasing. Recent studies showed a number of generalist phytoseiid species to be effective against both thrips and whiteflies in greenhouse crops (Nomikou *et al*., 2002; Messelink *et al*., 2006). The predator *Amblyseius swirskii* (Athias-Henriot) was one of the most promising candidates, and nowadays is widely used in various crops for control of these major pests. Our studies have shown that diversity of pest species can improve biological control by this predator: control of whiteflies in greenhouse cucumbers was considerably better in the presence of thrips (Messelink *et al*., 2008) and control of spider mites was much better in presence of thrips or whiteflies and the best in presence of both (Messelink *et al*., in prep.). This indirect interaction between pest species sharing a natural enemy has been classified as apparent competition (Holt, 1977). In this phenomenon, the density of one pest species increases the density of a shared predator, thereby decreasing the density of the other pest. Moreover, it was shown in laboratory experiments, that juvenile mortality of the predator was higher and developmental time was longer on diets of only thrips or only whiteflies than on a mixed diet of these pest species (Messelink *et al*., 2008).

The results of these studies suggest that is might be advantageous to allow some pest species diversity at the start of the cultivation, rather than try and exterminate all phytophagous species present. Even releasing pest organisms deliberately to enhance control of another pest may be considered. The adoption of “pest-in-first” with spider mites to enhance establishment of *Phytoseiulus persimilis* in sweet pepper shows that at least some growers are prepared to accept such strategies. Releasing thrips to improve whitefly control is generally considered too risky because of the low damage threshold. Introducing some greenhouse whiteflies was believed to be more acceptable. In this study we investigated the
possibility of improving control of western flower thrips, *Frankliniella occidentalis* (Pergande), by releasing greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), in the presence of the shared predator *A. swirskii*.

**Material and methods**

The experiment was carried out in 9 insect-proof greenhouse compartments of 24 m² each. A compartment contained 16 plants of the mildew resistant cultivar Shakira. The average temperature and relative humidity were 23ºC and 70% RH, respectively. We compared the following treatments in 3 replicates: (1) only thrips, (2) thrips plus a low initial whitefly density and (3) thrips plus a high initial whitefly density. The experiment started in April 2007 and lasted 10 weeks. The pest species were released in the first week, shortly after planting. Thrips, collected from chrysanthemum, were released at densities of 20 females per plant. Whiteflies, collected from tobacco, were released at densities of 10 or 100 adults (47% females) per plant. One week later, we introduced 15 females of the predatory mite *A. swirskii* from a laboratory culture to each plant. Predator and pest densities were monitored for eight weeks by weekly collecting six randomly chosen young leaves per compartment. All stages of both pest species were counted in the laboratory under a binocular microscope. For statistical analyses, we used a repeated measures ANOVA which was performed on the log(x+1) transformed numbers of predators and pests.

**Results and discussion**

The predator *A. swirskii* was present in considerable numbers in treatments with thrips only, but in even higher density in the presence of both pests (Figure 1). Nevertheless, thrips control was not better in the presence of whiteflies. Thrips was eventually controlled in all treatments, but there was a serious delay in the greenhouse compartments with whiteflies (Figure 2). Hence, we achieved the opposite of what was intended. High numbers of whitefly eggs on a critical moment (Figure 3) may explain this phenomenon. At the exact moment when thrips levels were decreasing in the compartments with thrips only (between the fifth and seventh week), a large second generation of whiteflies appeared in the other compartments, resulting in an enormous surplus of predator food. This probably led to predator satiation, thus releasing the thrips population of predation, resulting in delayed thrips control. Such predator-mediated interactions between prey species have been referred to as apparent mutualism (Holt & Lawton, 1994; Abrams & Matsuda, 1996) and are generally considered to occur at short time scales (Harmon & Andow, 2004; van Veen *et al.*, 2006). This study, however, proves that apparent mutualism can occur repeatedly in cases where populations fluctuate, which obviously happens when high pest densities are released at once.

We suggest that releases of lower densities of whiteflies and more spread through time might prevent predator satiation and as a result be more successful in improving thrips predation. In further trials we will try to work out this concept of apparent competition for biological control.

**Acknowledgements**

This study was supported by the Ministry of Agriculture, Nature and Food Quality. Pierre Ramakers is thanked for his comments.
Figure 1. Average densities (± s.e.m) of the predatory mite *A. swirskii* in the presence of thrips, or in the presence of both thrips and whiteflies. Pests were released in week 1 and the predators in week 2.

Figure 2. Average densities (± s.e.m) of thrips larvae in presence or absence of whiteflies. Whiteflies were released in low and high densities in week 1.
Figure 3. Average densities (± s.e.m) of whitefly eggs in treatments with low and high release densities. In both treatments thrips were also released.

References

Improving thrips control by the soil-dwelling predatory mite

*Macrocheles robustulus* (Berlese)

Gerben Messelink, Renata van Holstein-Saj

*Wageningen UR Greenhouse Horticulture, PO Box 20, 2265 ZG Bleiswijk, The Netherlands, E-mail: gerben.messelink@wur.nl*

**Abstract:** The predatory mite *Macrocheles robustulus* (Berlese) is frequently observed in greenhouse soils. A cage experiment was set up to assess the effects of this predator on western flower thrips in comparison with *Hypoaspis aculeifer* (Canestrini). *M. robustulus* controlled thrips significantly better (up to 70% reduction) than *H. aculeifer* (up to 50% reduction). Population build-up of soil-dwelling predatory mites was assessed in a freesia glasshouse. *M. robustulus* and *Hypoaspis miles* (Berlese) were introduced after soil sterilisation. *M. robustulus* reached densities up to 2800/m², whereas the maximum observed density of *H. miles* was 340/m² only.

**Key words:** biological control, *Frankliniella occidentalis*, Macrochelidae, Laelapidae, *Hypoaspis*

**Introduction**

For thrips species that leave their host plant for pupation (*Frankliniella occidentalis* (Pergande), *Thrips tabaci* (Lindeman)), predation on pupae and pre-pupae in the soil may contribute to control. A wide range of soil-dwelling predatory mites have the potential to prey on these stages (Karg, 1993). Today, two species are commercially applied as biological control agents, namely: *Hypoaspis* (*Stratiolaelaps*) miles (Berlese) and *Hypoaspis aculeifer* (Canestrini) (Acari: Laelapidae). Monitoring soil micro-arthropods after mass releases of these predators show, however, that they not always establish very well. *Macrocheles robustulus* (Berlese) (Acari: Macrochelidae) is often found spontaneously occurring in high numbers in greenhouse soils. A study with compost showed that this species can be very dominant in soils and a strong effect on thrips in chrysanthemum was suggested to be caused by this predator (Messelink & de Kogel, 2005). The objective of the present study was to assess the effects on thrips and population development in soil in comparison with commercially applied *Hypoaspis* species.

**Material and methods**

**Effects on thrips**

The effects of two release densities of the predators *M. robustulus* and *H. aculeifer* on western flower thrips, *F. occidentalis* were compared with an untreated control in a cage experiment in 4 replicates. The cages were made of transparent plastic cylinders (diameter 30 cm, height 40 cm) with fine insect gauze on top. In each cage one chrysanthemum plant (c.v. Mirimar) was placed in a 2.5 l pot with a diameter of 23 cm, shortly after the first flowers appeared. These pots were filled with clean potting soil, in which, however, occasional predatory mites (*H. aculeifer*) were detected near the roots. Fifty female thrips, collected from chrysanthemum, were released in each cage. After one week, 50 or 250 female predatory mites per cage were added. At the same time, we added a yellow sticky plate to each cage for capturing thrips adults emerging from the soil. Cages were placed in a laboratory under
artificial light of 12 h/day and a mean temperature of 21°C. After four weeks, we collected sticky plates and counted the captured thrips. Numbers of soil microarthropods (including the predatory mites) were assessed in a 500 ml soil sample taken from each pot. They were extracted by heat using Tullgren funnels, collected in 70% ethanol, filtrated over paper and identified under a binocular. All predatory mites were slide-mounted for species identification. Results were analysed by ANOVA on the log transformed numbers of thrips and predatory mites, followed by Fisher’s LSD test (p<0.05).

Population development of predators in a sterilized greenhouse soil
The establishing of *M. robustulus*, *H. miles* and a combination of both was tested in a large scale greenhouse experiment where freesia’s were cultivated on a loamy soil. Soils were covered after planting with a mulch layer of sawdust and granules of styrofoam. The mean soil temperature during the experiment was 16°C. The experiment was set up in two block replicates with large plots of 700 m². The predators were introduced in March, within 2 weeks after soil steaming. The release rate was 2 × 100/m² with an interval of a week. In the combination treatment, we released the same predator densities per species as in the single predator treatment, so in total 2 × 200/m². Predator populations were monitored by taking 250 ml soil samples/plot 5, 10 and 13 weeks after the first predator releases. Micro-arthropods were extracted and identified as described in the cage experiment. For statistical analyses we used a repeated measures ANOVA which was performed on the log(x+1) transformed numbers of predators.

Results

Effects on thrips
The best control of thrips was achieved with *M. robustulus*. Both low and high densities significantly reduced thrips populations, with 66 and 70% respectively. *H. aculeifer* significantly suppressed thrips at the high dosis treatment only, resulting in a reduction of 51% (Figure 1). Both doses of *M. robustulus* were significantly better in controlling thrips than the same doses of *H. aculeifer*. There was no significant difference between high and low release rate, neither in thrips nor in predators.

Equal release numbers of *H. aculeifer* and *M. robustulus* did not significantly differ in their final population densities (Figure 2). Both predator species developed well, resulting in densities of 15 to 38 mites/sample, equivalent to 1,800 to 4,500 mites/m².

The low initial contamination of the potting soil with *H. aculeifer* produced a considerable population in the control plots, equal to the low release density of this species. Releases of *M. robustulus* seem to have suppressed the development of *H. aculeifer* (Figure 2).

Population development of predators in a sterilized greenhouse soil
*M. robustulus* established very well and developed significantly better than *H. miles*, resulting in a ten times higher population level on average (Figure 3). Converted densities of *M. robustulus* varied between 2,000 to 2,800/m², whereas the converted levels of *H. miles* stayed between 140 and 340 predators/m². In the mixed treatment, *H. miles* could only be detected in the first assessment, and seems to have disappeared after that. In the last assessment, only *M. robustulus* was recovered, though in lower numbers than after separate release (Figure 3).
Figure 1. The average densities (± s.e.m.) of thrips captured on yellow sticky plates hanging over chrysanthemum plants in cages during four weeks after adding soil-swelling predatory mites.

Figure 2. The average densities (± s.e.m.) of *H. aculeifer* and *M. robustulus* in potting soil with chrysanthemum four weeks after introducing the predators.

**Discussion**

The cage experiment showed that *M. robustulus* is a better thrips predator than *H. aculeifer* at equal predator densities. Other studies have shown that *H. aculeifer*, in turn, is a better thrips predator than *H. miles* (Berndt *et al.*, 2004). For one, *M. robustulus* is a larger species (length of ♀ dorsal shield 710-770 µm) than *H. aculeifer* (length of ♀ dorsal shield 520-685 µm) (Costa, 1966; Karg, 1993). Moreover, we showed that *M. robustulus* reaches much higher population...
levels in a sterilized soil. Mites of the family Macrochelidae are often associated with dung breeding flies and are known as important predators of dipteran pest species (Halliday & Holm, 1987; Krantz, 1998). Important target pests in greenhouse crops are Sciaridae and Delia spp. Further research should address the benefits of introducing such predators from mass-rearings, as well as stimulating resident populations.

Figure 3. The average densities (± s.e.m.) of the predatory mites *M. robustulus* and *H. miles* in soil samples from a freesia crop. Species were released separately and mixed in week 1 and 2.

**Acknowledgements**

This study was supported by the Dutch Product Board for Horticulture and the Ministry of Agriculture, Nature and Food Quality. We thank Sandra Mulder from Koppert BV for mass rearing *M. robustulus* and Farid Faraji for confirming the identification of *M. robustulus*.

**References**

Biological control of whitefly in poinsettia in Ontario, Canada

Graeme Murphy¹, Mike Short², Ann Marie Cooper³, Margarethe Fast⁴, David Neal⁵
¹Ontario Ministry of Agriculture and Food, Vineland ON L0R 2E0, E-mail: graeme.murphy@ontario.ca; ²EcoHabitat Agri Services, Puslinch ON, N0B 2J0; ³Plant Products Co. Ltd., Brampton, ON L6T 1G1; ⁴Global Horticultural, Beamsville, ON, L0R 1B; ⁵Koppert Canada, Scarborough, ON M1X 1E4

Abstract: Trials demonstrating the use of biological control of whiteflies in poinsettia were carried out in commercial greenhouses in 2006 and 2007. Control was successful in nine out of twelve crops in 2006 and eight out of eleven in 2007. The trials are described and reasons for success and failure discussed.

Key words: biological control, whiteflies, poinsettia

Introduction

Until the mid-1980s, the primary pest species of whitefly in poinsettia was Trialeurodes vaporariorum, however at that time the emergence of Bemisia tabaci changed the pest dynamics of the crop. Successful control of T. vaporariorum has been demonstrated in poinsettia using the parasitoid Encarsia formosa (McMahon et al., 1992), however it has been more difficult to successfully control B. tabaci. Various studies have met with some success using E. formosa and Eretmocerus eremicus (Albert, 1990; Hoddle et al., 1999), but commercial use of these parasitoids has not achieved the same results (K. Boelkmans, pers. comm.). In 2004, whitefly dynamics in poinsettia changed again with the discovery of the Q biotype of B. tabaci in the USA. The Q biotype is resistant to many currently registered insecticides (Dennehy et al., 2006), and has renewed the urgency for a consistently successful biocontrol program in poinsettia.

At about the time that Q biotype was found in the USA, a newly commercialised parasitoid of B. tabaci, Eretmocerus mundus, became available in North America. E. mundus has been successful against B. tabaci in vegetable crops in southern Europe (Stansly et al., 2005). This paper describes two years of trials in poinsettia greenhouses in Ontario, Canada.

Materials and methods

In June 2006, plans were presented to Ontario poinsettia growers for a whitefly biological control program and the request made for interested growers to participate. In 2006, 12 growers agreed to participate and in 2007, 11 growers. The average size of the poinsettia crops was 4,500 m² (range 1,000-12,000 m²) in 2006, and 4,800 m² (range 1,000-9,000 m²) in 2007.

The program focused on the release of E. mundus (for control of B. tabaci) and E. formosa for control of T. vaporariorum. Release rates for these two parasitoids were calculated so that the cost did not exceed CD1.00/m², a cost agreed to by growers in the program, as being typical of a pesticide based control program. E. mundus was released at a rate of 3/m²/week for 6 weeks (beginning when poinsettia cuttings were brought into the greenhouse), and then reduced to 2/m²/week for the following 6 weeks. E. formosa was
introduced at 1.5/m²/week for 6 weeks and reduced to 1/m²/week for a further 6 weeks. These introduction rates were based on the area of the crop at its final spacing. At these rates, the cost of the program was approximately $CD0.80/m². Adjustments to these introductions were made based on observations of whitefly species in the greenhouse (e.g. if no *T. vaporariorum* were observed in the first 2-3 weeks, *E. formosa* introductions were reduced or eliminated). All greenhouses in 2006 were monitored on a weekly basis; in 2007, nine out of the 11 were monitored regularly. A minimum of 100 plants was inspected for evidence of whitefly adults and late immature stages. Percentage of infested plants and the numbers of each whitefly life stage and species were recorded weekly.

Greenhouses using biological control were monitored until Week 44 (the end of October) in 2006 and Week 45 in 2007. At this stage of the crop, growers were confident in the outcome of the trial, and if no pesticides had been used to that stage, none were needed after. In both 2006 and 2007, the week after the final monitoring of the biocontrol greenhouses, 10 greenhouses that had used a conventional pesticide-based whitefly control program were also monitored and their whitefly populations compared to those crops where successful biological control had been used.

**Results and discussion**

In 2006, *B. tabaci* was present in all 12 greenhouses and was the predominant species in 10 of those. *T. vaporariorum* was found in all crops but regularly in only three, and was the predominant species in two of those. Nine crops were grown successfully without the need for any pesticide applications to control whitefly. Of the other three crops, one grower reverted to pesticides in early October, and two required clean up applications in October and November (a single application in one case, and several applications to one infested cultivar in the other).

In 2007, eight of the eleven crops where biological control was used needed no pesticides to control whitefly. In the nine greenhouses that were monitored regularly, *B. tabaci* was present in all of them. *T. vaporariorum* was found regularly in two crops, and predominantly in only one. In the three greenhouses where pesticides were used, the program ended in mid September in one, and early October in another, when whitefly populations reached unacceptable levels. In the third greenhouse, a single variety received two applications in late October.

In both years, whitefly populations in the successful biological control crops at the final monitoring count were compared to greenhouses using a pesticide control program (Table 1).

<table>
<thead>
<tr>
<th></th>
<th>Mean % infested plants</th>
<th>Mean # whitefly per plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biocontrol greenhouses (n=12)</td>
<td>14.7 ±18.8</td>
<td>0.47 ± 0.83</td>
</tr>
<tr>
<td>Pesticide greenhouses (n=10)</td>
<td>14.0 ±18.7</td>
<td>0.54 ± 0.82</td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biocontrol Greenhouses (n=9)</td>
<td>16.3 ± 9.7</td>
<td>0.37 ± 0.21</td>
</tr>
<tr>
<td>Pesticide greenhouses (n=10)</td>
<td>27.1 ± 19.2</td>
<td>1.40 ± 1.5</td>
</tr>
</tbody>
</table>

Figures 1 and 2 show the whitefly populations in 2006 and 2007. The more heavily weighted solid lines indicate those crops where pesticides were needed. In both years, crops with less
than 20% of plants with live whitefly at the end of October required no pesticides for whitefly control. Crops with more than 40% of plants infested used pesticides. In crops where whitefly was found on 20-40% of plants, the decision to use pesticides was less clear. In some cases pesticides were used and in others (e.g. one greenhouse in 2007), the grower did not feel that pesticides were needed. Individual decisions were based on the population distribution within the greenhouse, e.g. whether the population was evenly spread, or focused more heavily in one or two varieties.

Figure 1. Whitefly populations in 9 poinsettia crops using biological control, 2006.

Figure 2. Whitefly populations in 9 poinsettia crops using biological control, 2007.
The term “successful” as used in these trials defines a program where no pesticides were needed for whitefly control. It is appreciated that this narrow definition doesn’t acknowledge the “success” of trials where pesticide use is reduced. However, for the purposes of this study it is useful for differentiating the final outcome.

The trials in both 2006 and 2007 demonstrated the potential of biological control as a strategy against whitefly in poinsettia. Nine out of twelve crops in 2006 and eight out of eleven in 2007 were grown without the need for any insecticides against whiteflies. When populations in the biological control crops were compared at the end of the season to crops grown under a pesticide-based whitefly control program, no differences were found in either the percentage of plants on which whiteflies were found, nor in the mean number of whiteflies per plant.

Several challenges are faced by poinsettia growers using biological control for whiteflies. Firstly, established whitefly populations imported on cuttings will reduce the chances of success. In these trials, there was evidence that early whitefly populations played a role in the success of the program. In both years, in crops where biological control failed, higher than average whitefly numbers were found in the first 1-2 weeks of monitoring. Extreme examples included 15% of plants in one crop in 2006, and 51% of another in 2007 with evidence of live whiteflies in the first week. Secondly, pesticide residues applied to stock plants from which cuttings are taken, can delay the establishment of biological control agents, further decreasing the chances of success. Finally, knowing the pesticide history of cuttings, is important in the decision making process, but is not necessarily straightforward. Growers in these trials who asked for a pesticide history of the cuttings found it difficult or impossible to obtain the information they required.

Increasing levels of resistance to pesticides make biological control of whitefly the ideal alternative. These trials demonstrate that successful biological control in poinsettias is achievable at the introduction rates and costs described. However, it depends on access to clean cuttings and to the pesticide history of the cuttings purchased. An increasing number of poinsettia growers are using biological control, and this should be acknowledged by propagators with the production of cuttings that meet the needs of this particular target group.

References

Bug Gardens for education and research in conservation biological control and sustainable horticulture

Michelle Nakano, James Alan Matteoni
School of Horticulture and the Institute for Sustainable Horticulture, Kwantlen University College, Surrey, British Columbia, Canada V3W 2M8, E-mail: michelle.nakano@kwantlen.ca

Abstract: About five years ago a group of educators and researchers decided to design a garden for use in conservation biological control and sustainable horticulture. The goal was to develop a garden template that could be installed across Canada, using low maintenance, drought tolerant plants that would attract and support beneficial arthropods. The garden would include some standard hardy species that could be used across Canada, but also allow space for species that were either local favourites or regionally hardy. The gardens could be located at schools for teaching and research, or at greenhouses and nurseries as plant insectaries. One such garden, planted at Kwantlen School of Horticulture, has been extremely useful for demonstrating the principles of conservation biological control and sustainable horticulture in different classes, as well as encouraging student research projects. The garden provides an educational context that supports heterogeneous learning styles in situated and inquiry based learning.

Key words: conservation biological control, sustainable horticulture, learning styles, situated learning, inquiry based learning

Introduction

Five years ago a group of educators, researchers and integrated pest management (IPM) practitioners met to discuss the possibility of designing a garden template that could be replicated across Canada for use in education and research in conservation biological control. This group included Sophie Dessurault, Integrated Pest Management Coordinator, City of Vancouver Parks Board; Ken Fry, Instructor, Olds College, Olds, Alberta; Dave Gillespie, Research Scientist, Agriculture and Agri-Food Canada, Agassiz, BC; Peter Isaacscon, National IPM/Minor Use Coordinator, Canadian Nursery and Landscape Association, Surrey, BC; Jen Lleuwellen, Nursery Crop Specialist, Ontario Ministry of Agriculture and Rural Affairs, Guelph, Ont.; Jim Matteoni and Susan Murray, Instructors, Kwantlen School of Horticulture and the Institute for Sustainable Horticulture, Surrey, BC; and Mike Short, Eco Habitat Agri Services, Grimsby, Ontario.

Over the first year it was decided to limit the size of the garden template to approximately 200 m². The garden was to be based on the principles of sustainable horticulture (Poincelot, 2003). Plants would be installed and allowed two years to become established, before watering was reduced or eliminated. Species would include cultivars deemed acceptable for their garden value (colour, form and texture), and for low maintenance, disease resistance and pest tolerance. Species diversity would provide pollen and nectar across the growing season, as well as a variety of structure (height and density). The aphid predator-parasitoid system would be the focus for research and teaching purposes. Therefore, some plants would be included for supporting aphid infestations.

In British Columbia, the principal aphids in landscape gardens have been the green peach aphid *Myzus persicae* (Sulzer), and the melon or cotton aphid, *Aphis gossypii* Glover.
Common predators include *Aphidoletes aphidimyza* (Rondani), lady bird beetles *Hippodamia convergens* Guérin-Méneville and *Harmonia axyridis* (Pallas), green lacewings, *Chrysoperla (= Chrysopa) carnea* (Stephens) and several species of syrphid flies. *Aphidius* spp. are the most common parasitoid.

With a purpose of testing intentional planting for attraction and retention of beneficial insects for pest management and amenity, monitoring and identifying insect populations in connection with analysis of plant selection creates an effective model for inquiry based learning and applied research.

**Material and methods**

**Plant species choice**
The garden was designed around an existing, deciduous woody plant, *Acer palmatum* Thunb. Atropurpureum Group, and an inventory of proven herbaceous plants that included *Calamagrostis × acutiflora* (Schrad.) Rchb. ‘Karl Foerster’, *Rudbeckia fulgida* Aiton ‘Goldsturm’ and *Euphorbia polychroma (= Chamaesyce Gray) along an existing stone wall to provide good public exposure. A walkway was included to allow for closer inspection and easy access to plant material. Space was allowed for monitoring with yellow sticky cards and aphid predator-parasitoid trap plants. Sweet pepper plants (*Capsicum annuum* L.), infested with green peach aphids functioned as trap plants to encourage and detect oviposition of beneficial insects (Dave Gillespie, 2004). These were kept in the garden for one to two days.

Several garden species were included for their pollen and nectar production. Fennel, *Foeniculum vulgare* P. Mill. ‘Purpureum’, and sweet alyssum *Lobularia maritima* (L.) Desv. ‘Carpet of Snow’ and ‘Rosie O’Day’, were chosen to provide nectar throughout the growing season. Grasses, including *Miscanthus* sp. Anderss., provided copious pollen in late summer and autumn. Two different sections of semi-double roses with exposed pollen, *Rosa* L. ‘Ballerina’ and *Rosa* ‘Bonica’, were also included. Garden nasturtium, *Tropaeolum majus* L. ‘Alaska Series’, provided nectar and hosted aphid infestations.

**Installation, maintenance, and monitoring**
To aid plant establishment an irrigation system was installed. This was used only as needed in the first summer after planting. Weeding was done monthly. Yellow sticky cards (7.6 × 12.7 cm) were used for monitoring in five locations in the garden. A random 2.5 cm strip along the length exclusive of the margins was counted weekly. Hours were recorded for all activities.

**Educational opportunities**
The Bug Garden project enhanced student learning about horticultural practices and current issues in pest management and sustainable horticulture, by providing an appropriate model for situated learning. Learning was contextually situated and thus fundamentally influenced by the activities, context, and culture in which it was developed and used. Garden design, renovation, installation, and maintenance created diverse opportunities for technical practice and collaborative problem solving among peers within a culture of horticultural coaches.

**Results and discussion**
Students benefitted from the inclusion of the bug garden in several classes including landscape practices, irrigation and drainage, arboriculture, plant identification, and pest management. It was observed that aphid infestations came and went without any conspicuous damage to plants and that thrips populations were very high, but no injury was apparent. This
evidence of natural suppression, through the implementation of conservation biological control, transferred theory into practice. As a result graduates will be able to return to the project for continued learning or customer training.

In the first year of monitoring, background levels of many thrips and aphid parasitoids have been documented. Projects being planned for the garden include comparing alyssum cultivars for parasitoid preference, demonstrating garden monitoring to landscape professionals, developing landscape contracts that include integrated pest management options, and challenging the garden with aphid infested plants.

Bug Garden presentations (by students as well as faculty) have provided outreach opportunities and benefits for the public by enhancing understanding of horticultural issues related to sustainability. Ideas, initiatives, and techniques presented have provided alternate perspectives and methods for pest management and gardening practice.

The Bug Garden project utilizes the unique features of the horticulture education infrastructure in an innovative way that contributes to enhanced awareness and appreciation of Integrated Pest Management, and supports community transition toward sustainable horticulture.

Acknowledgements

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Ceratitis capitata larvae as an alternative food source for Macrolophus caliginosus

Mauro Nannini¹, Luca Ruiu¹, Ignazio Floris²
¹AGRIS Sardegna, V. le Trieste 111, 09123 Cagliari, Italy, E-mail: laiu@cras.sardegna.it; ²Dipartimento di Protezione delle Piante, University of Sassari, Via E. De Nicola, 07100 Sassari, Italy

Abstract: The suitability of mature larvae of the Mediterranean fruit fly, Ceratitis capitata, as an alternative food source for the predatory bug Macrolophus caliginosus, was evaluated in comparison with other standard preys. Our experiment results show that this fictitious prey is accepted by all stages of the mirid bug, although specimens reared on fruit fly larvae are not as performing as those reared either on T. vaporariorum immatures or E. kuehniella eggs. Nevertheless the use of this prey could be envisaged for mass rearing purposes in reason of its low cost.

Key words: biological control, fictitious prey, mass rearing, Mediterranean fruit fly

Introduction

Since its commercial launch, the mirid Macrolophus caliginosus Wagner has become one of the most successful beneficials for whitefly control in tomato greenhouses. Commercial mass rearing of this predatory bug is based on a diet consisting of Ephestia kuehniella (Zeller) eggs. However, different studies have demonstrated the possibility of culturing the predator on low cost alternative food sources, such as semi-artificial (Iriarte & Castañé, 2001) or artificial diets (Grenier et al., 1989), or dry Artemia sp. cysts (Riudavets et al., 2006).

At the experimental beneficial rearing facility (L.A.I.U.) of AGRIS Sardegna (Agricultural Research Agency of Sardinia, formerly C.R.A.S.) the Mediterranean fruit fly, Ceratitis capitata Wied. is used for mass rearing of the parasitoid Psyttalia concolor Szepl. Since 1997 L.A.I.U has been employing surplus fruit fly larvae as a cheap alternative food prey for M. caliginosus, replacing the previously used natural prey, the greenhouse whitefly Trialeurodes vaporariorum (Westwood). Although this method is feasible and extremely convenient in terms of time and labour saving, the quality of the predatory bugs produced is of major concern. The aim of the present work was to gather further information on the performance and some biological traits of M. caliginosus reared on a C. capitata-based diet.

Materials and methods

M. caliginosus specimens used in the experiments were collected from a colony maintained on tobacco plants and fed third instar C. capitata larvae, previously killed in hot water and stored at -20°C until use. The Mediterranean fruit fly rearing techniques and conditions were those used by the FAO/IAEA Laboratory in Seibersdorf (Austria) and L.A.I.U. (Brotzu et al., 1996). E. kuehniella eggs were supplied by Koppert B.V. (The Netherlands). All experiments were carried out at a temperature of 23.0 ±2°C, relative humidity of 70 ±20%, and a 14:10 (L:D) photoperiod.
In Experiment 1, immature development time and survival of *M. caliginosus* fed on a fruit fly diet were estimated in comparison with other food sources: the natural prey *T. vaporariorum* and the standard prey *E. kuehniella*. First instar nymphs were collected from tobacco plants on the day of eclosion, and after individual isolation in a ventilated plastic Petri dish (5.5–cm diameter) containing filter paper and a tobacco leaf disc, were offered weekly-refreshed *T. vaporariorum* nymphs and pupae (50-70), fixed on small pieces of tobacco leaves, *E. kuehniella* eggs (10 mg) or *C. capitata* larvae (1, 4, 8 or 16).

In Experiment 2, the influence of a *C. capitata* larvae-based diet on the reproductive potential of *M. caliginosus*, was studied according to the method developed by Perdikis (2002), with minor modifications. Newly emerged adult pairs (one female and one male) were maintained in a plastic cylinder where 10 weekly-refreshed fruit fly larvae were provided as food. A control where the mirid bug was offered no *C. capitata* larvae was also run. A stem of *Pelargonium zonale* (L.) inserted into moistened foam to prevent dehydration was used as oviposition substrate. Every two days, the stem was removed from the cylinder for egg counting and replaced by a new one. Stems were examined under a stereomicroscope after egg staining with safranin. The cylinder was checked daily for the presence of live females.

In order to compare fertility of mirid bugs reared on different prey diets, in Experiment 3 adults were separated into pairs (one female and one male), and each pair was reared in a 800-cc-ventilated plastic container enclosing a tobacco plantlet. To reduce any influence related to the previous rearing diet on reproductive performance, the insects were starved for 3 days before being subjected for one week to one of the following diets: 50-70 *T. vaporariorum* nymphs and pupae, 10 *C. capitata* larvae, 10 mg of *E. kuehniella* eggs, no prey (control). For fertility measurements, newly emerged nymphs were removed from the arena and counted twice a week.

Longevity of newly emerged adults (females and males) reared in pairs on tobacco plantlets as in Experiment 3, was evaluated in Experiment 4. In this case, the diet consisted of either weekly refreshed 50-70 *T. vaporariorum* nymphs and pupae or 10 *C. capitata* larvae.

Most of the experimental data were analyzed by one-way analysis of variance (ANOVA). Means were compared using Tukey’s HSD test. Where appropriate, data were log-transformed before analysis. Mortality rates were compared using a χ²-test. Data from Experiment 2 were analysed by t-tests to compare means of the two diet-groups.

**Results and discussion**

In Experiment 1, no differences were observed in either mortality rate or development time for *M. caliginosus* fed on *T. vaporariorum*, *E. kuehniella* eggs or 16 *C. capitata* larvae. By contrast, development time proved to be longer when a smaller number of *C. capitata* larvae were administered (Table 1).

The results of Experiment 2 are summarized in Table 2. In relation to the highly variable reproductive phase duration and longevity, no meaningful differences among different diets were evidenced. Females reared on fruit fly larvae showed a shorter average oviposition period (13.7 days) than those fed on *E. kuehniella* (56 and 30 days, at 20 and 25°C respectively) (Fauvel et al., 1987) or *T. urticae* (18 days at 22°C) (Hansen et al., 1999). Interestingly, in the same conditions, these females laid a significantly higher number of eggs than females fed on prey-free diets (Table 2). Although the average number of eggs laid by each female (31.2) reared on the fruit fly-diet was considerably lower than females reared by Fauvel et al. (1987) on *E. kuehniella* (125 eggs) or *T. vaporariorum* (86 eggs), their fecundity was more in line with the results reported by Hansen et al. (1999) on *T. urticae* (20 eggs).
Results of Experiment 3 showed a significantly lower fertility of mirid females fed *C. capitata* larvae in comparison with *T. vaporariorum* and *E. kuehniella*-based diets. However, female fertility was significantly higher than female fed on a prey-free diet (Table 3). Experiment 4 showed *Ceratitis* fed-adult lifespan to be significantly shorter (about half) than adults fed the natural prey *T. vaporariorum* (Table 3). In addition, male survived significantly longer than females, regardless of prey provided (Table 3). Despite some differences between Experiment 2 and Experiment 4, probably due to the different host plants used, in general longevity of females fed *C. capitata* (38 days) was shorter than that reported by Fauvel et al. (1987) for females fed *E. kuehniella* (40 days at 25°C; 84 days at 20°C), but longer than that reported by Hansen et al. (1999) for a *T. urticae* diet (29 days at 22°C).

Table 1. Mean development time (± s.e.) and mortality of *M. caliginosus* nymphs reared on *C. capitata* larvae (Cc), *E. kuehniella* eggs (Ek) or *T. vaporariorum* nymphs/pupae (Tv).

<table>
<thead>
<tr>
<th>Prey offered</th>
<th>Tv</th>
<th>Cc</th>
<th>Ek</th>
</tr>
</thead>
<tbody>
<tr>
<td># (or weight (mg))/week</td>
<td>50-70</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>n</td>
<td>17</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>Development time</td>
<td>20.9±0.5a</td>
<td>22.1±0.9ab</td>
<td>23.6±0.5b</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>10.5A</td>
<td>12.5A</td>
<td>11.1A</td>
</tr>
</tbody>
</table>

*a*number of nymphs examined; *b* days; *c* means within rows followed by different letters are significantly different according to Tukey’ HSD test (small letters) and χ² test (capital letters) (p< 0.05).

Table 2. Mean (± s.e.) oviposition period duration, longevity and fecundity of *M. caliginosus* adults reared on 10 weekly-refreshed *C. capitata* larvae.

<table>
<thead>
<tr>
<th>Diet</th>
<th>n</th>
<th>Oviposition period</th>
<th>Fecundity</th>
<th>Longevity</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. capitata</td>
<td>13</td>
<td>13.7 ± 1.7a</td>
<td>31.2 ± 2.0a</td>
<td>30.0 ± 2.2a</td>
</tr>
<tr>
<td>No prey</td>
<td>14</td>
<td>9.4 ± 1.4a</td>
<td>12.9 ± 1.2b</td>
<td>22.9 ± 1.4a</td>
</tr>
</tbody>
</table>

*a* number of females examined; *b* days; *c* eggs/female; *d* means in each column followed by different letters are significantly different (t-test, p< 0.05).

Table 3. Mean (± s.e.) fertility and longevity of *M. caliginosus* reared on *C. capitata* larvae (Cc), *E. kuehniella* eggs (Ek), and *T. vaporariorum* nymphs/pupae (Tv), or with no prey.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Prey offered</th>
<th>Tv</th>
<th>Cc</th>
<th>Ek</th>
<th>No prey</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td>50-70/week</td>
<td>10/week</td>
<td>10 mg/week</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Fertility</td>
<td>2.7±0.4a</td>
<td>1.3±0.2b</td>
<td>2.6±0.4a</td>
<td>0.4±0.1c</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Longevity</td>
<td>111.5±3.4a</td>
<td>68.9±5.0b</td>
<td>65.9±5.9b</td>
<td>38.2±3.8c</td>
<td></td>
</tr>
</tbody>
</table>

*a* number of females examined; *b* nymphs/♀/day; *c* days; *d* means within rows followed by different letters are significantly different (Tukey’s HSD test, p< 0.05).
The results of our experiments showed diminished biological performance (fecundity, fertility and longevity) in *M. caliginosus* reared on a diet including *C. capitata* larvae as prey, compared to diets based on *T. vaporariorum* and *E. kuehniella*. However, only minor adverse effects were associated to nymphal development. On the other hand, the *C. capitata* diet proved to be as efficient as the *T. urticae*-diet used by Hansen *et al.*, (1999), who concluded that this prey was inadequate to sustain good *M. caliginosus* physiological performances. However, it is essential to consider that the presence of *C. capitata* improved significantly the mirid performances in comparison with a prey-free diet. Finally, with regard to the significant post-mortem alterations of mature *C. capitata* larvae, more frequent refreshing is expected to provide a higher quality food and, as a consequence, better performing *M. caliginosus* specimens (Grenier *et al.*, 1989).

The present study confirms *C. capitata* as a suitable diet for the different stages of *M. caliginosus*, though not as effective in nutritional terms as diets based on the natural prey *T. vaporariorum* or the standard commercial prey *E. kuehniella*. However, *C. capitata* larvae are an attractive option for *M. caliginosus* mass rearing as they are less expensive, especially for rearing facilities like L.A.I.U., where *C. capitata* mass rearing is already carried out for different purposes. Finally, further investigations are needed to study in greater depth the potential of this prey as an alternative food source for the mirid bug and other beneficials. In fact, the development of new methods and techniques for killing, storing and offering this prey could improve its suitability as a feeding substrate for the mass culture of predaceous insects.

**Acknowledgements**

We are grateful to Dr. Giuseppe Conti and Dr. Salvatore Spanedda for their help in conducting experiments during their internship in the Department of Plant Protection (Sassari University).

**References**


A novel use of *Ceratitis capitata* for biological control programs

Mauro Nannini, Francesco Foddi, Giovanni Murgia, Riccardo Pisci, Francesco Sanna

AGRIS Sardegna, V. le Trieste 111, 09123 Cagliari, Italy, E-mail: laiu@cras.sardegna.it

Abstract: Fruit flies are currently reared worldwide for IPM purposes (SIT programs, parasitoid rearing). In the present work a novel use of the Mediterranean fruit fly, *Ceratitis capitata*, as food source for *M. caliginosus* is proposed. Quality control tests have shown that the mirid bugs reared on a fruit fly larvae-based diet meet quality standards proposed by IOBC for this beneficial. Individuals fed the fictitious prey exhibit similar predation efficiency to insects reared on the natural prey *Trialeurodes vaporariorum*. On the other hand, the availability of *C. capitata* larvae on tomato plants failed to enhance the establishment of the predatory bug in commercial crops.

Key words: banker plants, fictitious prey, inoculative releases, mass rearing, Mediterranean fruit fly

Introduction

Millions of *Ceratitis capitata* Wied., the Mediterranean fruitfly are currently reared every week for IPM purposes. The great majority of these flies are employed in SIT programs, but the insect is also used as unnatural host for tephritid parasitoids. A study carried out by Liquido and Nishida (1985) showed that fruit fly eggs are also suitable for feeding the mirid *Cyrtorhinus lividipennis* Reuter. Following this line of investigation, the Beneficial Insect Rearing Laboratory (L.A.I.U.) of AGRIS Sardegna (formerly C.R.A.S.) has developed a culturing method for the mirid *Macrolophus caliginosus* Wagner based on the use of *C. capitata* mature larvae as food source.

The release of the mirid bug in tomato greenhouses is presently standard pest control practice in several horticultural areas of Europe. However the results achieved in whitefly control may be affected by a poor establishment of the beneficial on the crops. Since prey scarcity is one of the factors that may seriously reduce *M. caliginosus* population growth, provision at release points of an alternative food source, like *Ephestia kuehniella* (Zeller) eggs, has been proposed by some producers of beneficial insects. Furthermore other novel release methods such as the use of banker plants or releases in nurseries envisaged the use of moth eggs to enhance mirid bug establishment (Maisonneuve et al., 1997; Lenfant et al., 2000).

The present work presents the results of experiments recently carried out to evaluate the suitability of the Mediterranean fruit fly as food source for producing *M. caliginosus* individuals that perform adequately in the field and improving the efficacy of inoculative releases of the beneficial.

Materials and methods

The mirid bugs tested in this study were reared on tobacco plants, fed with *C. capitata* third instar larvae or greenhouse whiteflies, *Trialeurodes vaporariorum* (Westwood), according to the experimental design. Mature larvae were killed in hot water and stored in a freezer,
defrosted and mixed with vermiculite before use. Laboratory experiments were carried out at a temperature of 23.0 ±2°C, relative humidity of 70 ±20%, and a 14:10 (L:D) photoperiod.

To assess the suitability for inoculative release programs of individuals fed on fruit fly diet, a series of tests was performed adapted from IOBC/EC quality control guidelines (van Lenteren et al., 2003). One thousand adult mirids, collected, packed and stored following standard procedures applied at L.A.I.U. for field experiments (100 insects per 150-cc plastic container lined with soft paper; one-day storage at 8°C) were examined to estimate sex ratio and mortality. In order to evaluate predatory bug fertility, thirty females randomly selected from a single container were individually isolated for three days on tobacco plantlets in 800-cc ventilated plastic cages and fed with fruit fly larvae. Newly emerged nymphs were counted and collected every 2-3-days.

To investigate predation efficiency of *M. caliginosus* fed on the fictitious prey, the number of greenhouse whitefly pupae consumed during a 48-hour period by adult females previously fed with *C. capitata* larvae or the natural prey *T. vaporariorum* were compared. Each predatory bug was isolated in a 9-cm-diameter ventilated Petri dish, where a tobacco leaf disk was placed upside down on an approximately 0.5-cm thick layer of agar. Twenty-five whitefly pupae fixed on small pieces of tobacco leaves were offered at the beginning of the experiment and after 24 hours. Each treatment was repeated 20 times.

The effect of a fruit fly diet on *M. caliginosus* population growth was evaluated for three different patterns of prey distribution: concentrated on a single tobacco plant, according to the banker plant release method (“banker plant” pattern), dispersed among tomato plants (“tomato plants” pattern), or no prey (“unfed control” pattern). Fifty adults (30 ♀♀ and 20 ♂♂) and 50 nymphs were released in net cages housed in an experimental glasshouse. Each cage contained 10 tomato plants, plus one tobacco plant in banker plant cages. Twenty fruit fly larvae per individual released were supplied weekly, except in the unfed control cages. The number of mirid bugs present on tomato and tobacco plants was counted 8 weeks after release (testing period: March-May). Each treatment was replicated 3 times.

The use of *C. capitata* larvae for improving *M. caliginosus* establishment on tomato crops was also studied in commercial greenhouses. In two beefheart tomato crops of approximately 2,000 m², planted respectively in September and October, 10 release points were set up, each consisting of a 3-stem plant. In five randomly selected introduction points 20 fruit fly larvae per mirid bug released were provided four times at 7-day intervals, starting from the day of beneficial introduction, sprinkling them directly onto tomato leaves or on plastic dispensers fixed to the stems. Predators were released about four weeks after transplant in clusters of 50 individuals (25 adults and 25 nymphs) per distribution point. To monitor mirid occurrence in the introduction areas, one stem of 13 crosswise-arranged plants, the middle plant coinciding with a release point, was checked for predatory bugs on weeks 1, 3, 6 and 9 after release.

Experimental data were analyzed by t test or one-way analysis of variance (ANOVA). Means were compared using Tukey’s HSD test.

**Results and discussion**

Though the percentage of females observed in 1,000 individuals was 39.5 ±3.2% (mean ±s.e.; n = 10), lower than the value indicated in the IOBC guidelines for *M. caliginosus* (> 45%), mortality (3.8 ±1.3%; n: 10) met quality standards (<5%). Mean fertility (10.7 ±1.0 nymphs/female) was higher than fecundity requirements for a 3-day oviposition period (>4 eggs/female). These results show that the culturing method proposed may produce predators meeting mortality and fecundity standards. The prevalence of males in the samples examined
does not necessarily reflect the actual sex ratio of colonies reared on a fruit fly diet but could depend on sex-related differences in within-plant distribution and detectability. No difference in the number of preys consumed by adult females reared on *C. capitata* (28.4 ±4.3) and greenhouse whitefly (32.1 ±3.8) was observed. Therefore predation efficiency does not seem to be affected by rearing *M. caliginosus* on fruit fly larvae. Similar results were achieved by Castañé and Zapata (2005) for *M. caliginosus* reared on *E. kuehniella* eggs and a meat diet (26.6 and 26.4 pupae/female, respectively).

The number of mirid bugs recorded in cages provided with *C. capitata* larvae was significantly higher than in those containing unfed predators (Table 1). This confirms that the fictitious prey may sustain predator performance, no matter whether directly distributed on tomato plants or concentrated on a banker plant. Introduction of a tobacco plant as alternative host did not yield any significant increase in mirid numbers (Table 1), presumably due to the fact that in our experiment tomato plants did not undergo ordinary cultural practices, like leaf removal, which may limit the establishment of the predatory bug. Furthermore, considering that approximately one third of the individuals were found on tobacco plants (data not shown), *M. caliginosus* showed a slight tendency to remain on banker plants rather than move to tomato plants, as already reported in other studies (Fisher, 2003; Schoen, 2003).

Table 1. Progeny of 50 *M. caliginosus* subjected for 8 weeks to the following feeding regimes: 10 fruit fly larvae/mirid/week, supplied on tomato plants or on a tobacco banker plant, or no prey supplied.

<table>
<thead>
<tr>
<th>Feeding regimes</th>
<th>10 fruit fly larvae supplied on</th>
<th>No prey supplied</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tomato plants</td>
<td>Banker plant</td>
</tr>
<tr>
<td>Mean number of</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>M. caliginosus</em></td>
<td>723.3 ± 31.2 a</td>
<td>623.7 ± 32.0 a</td>
</tr>
<tr>
<td></td>
<td>247.7 ± 35.4 b</td>
<td></td>
</tr>
</tbody>
</table>

Means within rows followed by the same letter do not differ significantly according to Tukey’s HSD test (p < 0.05).

Contrary to the results of the previous experiment, no difference in the number of predatory bugs was observed in commercial crops in release areas where fruit fly larvae were supplied or not (Figure 1). This may be explained by the mirid bugs spreading through the crop after release, which does not happen in experiments performed in confined arenas, and this may have limited the number of individuals actually feeding on the prey offered. Another limitation of this release method is that *C. capitata* larvae do not adhere to tomato leaf surface and easily drop off during handling, reducing prey availability.

The study carried out shows that *M. caliginosus* reared on a *C. Capitata* diet are suitable for use in biological control programs. This confirms the positive results achieved using mirid bugs fed on fictitious prey for inoculative releases in Sardinian tomato greenhouses. In the experiments carried out in commercial crops the availability of fruit fly larvae as a food source alternative to natural preys did not produce any increase in predator numbers. However, further work is necessary to gain a better understanding of the potential of *C. capitata* larvae for enhancing the establishment of the predatory bug in protected tomato crops.
Figure 1. Number of *M. caliginosus* present 1, 3, 6 and 9 weeks after predator release, in proximity of five introduction points where 20 *C. capitata* mature larvae/mirid/week were supplied or not supplied; no difference between treatments was evidenced by t test (p > 0.05).

References


Some pest problems and solutions in Swedish organic greenhouse production

Barbro Nedstam
Swedish Board of Agriculture, Plant Protection Centre, Box 12, SE-23053 Alnarp, Sweden, E-mail: barbro.nedstam@sjv.se

Abstract: Plant protection in organic greenhouse production relies heavily on pest control with natural enemies. In Sweden organic growers can often but not always rely upon experience of pest control in IPM production. In this overview the pest situation in solanaceous crops and in blueberries and blackberries is discussed. The need for additional low-risk pest control products is obvious but hampered by present registration costs.

Key words: pests, biological control, organic production, registration

Introduction

Organic greenhouse production is small in Sweden, covering about 10 ha in 2006. A wide range of vegetables, herbs and soft fruits are grown. Many crops have specific pests, although major pests like spider mites and some aphid species are present in mostly all production systems. In order to increase production more knowledge and experience of safe and reliable pest control methods is needed. This encompasses biological pest control and the use of supporting treatments with insecticidal soaps, plant extracts and other control methods accepted in organic crops. Often experience can be drawn from biocontrol being used in standard IPM greenhouse production. Generally higher numbers of predators and parasitoids than in IPM are introduced to safeguard good aphid control – aphids being the number one pest as a whole in organic production. Spider mites are controlled with predatory mites and by spraying water. For thrips control preventive methods are recommended. Whiteflies are still minor pests in Sweden, and control is based on monitoring. This is also the case with leafminers. Some horticultural crops can only be grown with organic methods, partly due to the lack of pesticide registrations for very minor crops. This means there is no general, national plant protection know-how to build upon when handling the various problems that may turn up. Furthermore, pest control has to be carried out with the help of non-chemical methods only.

Here two different, practical examples will be discussed: Pest control in Solanaceous crops and in berries (blueberries and blackberries).

Solanaceous crops

Aphids
In sweet pepper and chili pepper several aphid species can occur, Myzus persicae and Aulacorthum solani being the most common. Banker plant systems with Aphidius colemani and A. ervi normally work well but there are cases when hibernating gall midges, Aphidoletes aphidimyza, are severely disturbing the build-up of parasitoids. Additional weekly releases of parasitoids must then be carried out, as A. aphidimyza used alone is seldom a satisfactory
plant protection tool. Spontaneous occurrence of *Praon volucre* is rather common. When other aphid species are present the control can be more problematic. *Aphis nasturtii* seems to be difficult to control with these natural enemies. An infestation in sweet pepper went out of control though large amounts of natural enemies were introduced. If the failure could be due to *Amblyseius swirskii* being applied against thrips was never clarified, but could maybe be suspected as these predatory mites can feed on the eggs of the gall midge (Messelink, 2007).

**Mites**

Control of spider mites (*Tetranychus urticae*) can be achieved by using *Phytoseiulus persimilis*. *Feltiella acarisuga* is presently not registered for use in Sweden, but often occurs spontaneously. Attacks by parasitoids on the larvae are common from August onwards, limiting their contribution to spider mite control. *Polyphagotarsonemus latus* and *Aculops lycopersici* seem to occur more frequently than in IPM production. *Neoseiulus cucumeris* and *Amblyseius swirskii* work well against *P. latus* in sweet pepper and chili, but we have no predatory mite against these pests suited for use in a tomato crop. Spraying with biorational products like Eradicoat T can solve the problem.

**Woodlice**

Newly planted tomatoes are often suffering from damage by *Armadillidium nasatum* and other pill bug species. Pest populations can increase tremendously at an early crop stage, and young plants can succumb to heavy feeding on stems. Various methods of helping the plants through the sensitive, soft stage are being practised. One is to place bands of grass clippings at a short distance from the plant rows, attracting the pest to this alternative feed. Another is “painting” the stems with a chalk powder suspension, which gives some protective effect.

**Blackberries and blueberries**

**Aphids**

In blackberry crops *Aphis ruborum* tends to establish permanently. Early infestations develop from winter eggs on the canes. In summer a dwarf aphid form dominates. These tiny individuals are neither a suitable prey for gall midge larvae nor for hosting parasitoids. Spontaneously occurring ladybug larvae have been found in aphid colonies, but generally the growers must resort to spray programmes with insecticidal soap. Blueberries suffer from an exotic species, the North American aphid *Ericaphis* (*Fimbriaphis*) *scammelli*. This species has also been found in Italy (Barbagallo *et al.*, 1998). It has been quite easy to control with *A. aphidimyza*.

**Mites**

*T. urticae* in blackberries is easy to control with *P. persimilis*, but when *Panonychus ulmi* is the dominating species, we are in trouble. *Amblyseius andersoni* has been tried on a small scale and proved quite useful, but the Swedish market is still too small to financially motivate a registration.

**Gall midges**

A special problem in blueberries is the North American species *Dasineura oxycoccana*. Larvae feeding in shoot tips cause damage to plant growth. This species was also found in Italy (Bosio *et al.*, 1998). Injury in older plants has been limited, probably due to a parasitoid (*Synopeas* sp.) regulating the population. For the grower the gall midge can even be regarded as a bit useful as less pruning work is needed.
Concluding remarks

Swedish regulations concerning natural enemies and the costs for registrations have resulted in a comparatively short list of parasitoids and predators available to our growers. There is a need for additional species like *A. andersoni*, *A. californicus*, *F. acarisuga*, *Orius laevigatus* and many more. Also a formulation of *Beauveria bassiana* accepted in organic production would be very useful to have, as would neem extracts. Steps in the direction of supporting low-risk plant protection products would certainly mean a lot to the expansion of organic production in Sweden.

Acknowledgements

Thanks to Victor F. Eastop, Raymond J. Gagne and Blair J. Sampson for insect identification.

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Potential of entomopathogenic fungus *Isaria fumosorosea* to protect potted ornamental plants against *Bemisia tabaci* during shipping

Lance S. Osborne¹, Zdenek Landa², Andrea Bohata², Cindy McKenzie³

¹Mid-Florida Research & Educational Center, IFAS, University of Florida, 2725 Binion Road, Apopka, FL 32703-8504, USA, E-mail: Isosborn@ufl.edu; ²Department of Plant Sciences, Faculty of Agriculture, University of South Bohemia, Studentska 13, 370 05 Ceske Budejovice, Czech Republic; ³US Horticultural Research Laboratory, ARS-USDA, 2001 South Rock Road, Fort Pierce, FL 34945, USA

Abstract: The efficacy of entomopathogenic fungus *Isaria fumosorosea* has been evaluated under abiotic conditions similar to those typical for shipping of ornamental plants. When applied to a synchronized population of *B. tabaci* L4 nymphs on poinsettias, *I. fumosorosea* induced mortality even in regime of low temperature. The efficacy of this fungus was increased by dose, application of pre-germinated conidia and additional nutritional supplements. In some treatments, the population of *B. tabaci* was practically eradicated and there were no symptoms detected which would indicate a fungus related phytotoxicity.

Key words: *Bemisia tabaci*, *Isaria fumosorosea*, shipping, poinsettia, temperature regime

Introduction

Introduction of non-indigenous species have increased with expanding global trade. Also, many indigenous plant pest species are disseminated on infested host plants through foreign and national trade during shipping. Effective precautions aimed to prevent or minimize involuntary human mediated introduction of pests into new regions are therefore required (Work et al., 2005). Whiteflies represent a typical group of pests being disseminated with host plants during shipping, because of the close relation all immature stages have with their host plants. Quite strict rules were developed and applied recently to prevent the dissemination of *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae), which may have significant impact to trade and the cost of protective programs (Van Driesche et al., 2002), particularly when special pre-shipping treatments aimed to eradicate whiteflies before and during shipping must be applied. Besides insecticides, various mitosporic entomopathogenic fungi were evaluated for their potential to eradicate *B. tabaci* (Faria & Wright, 2001), including *Lecanicillium muscarium* (Cuthbertson et al., 2005), *Paecilomyces fumosoroseus* (Osborne & Landa, 1992) and *Beauveria bassiana* (Wraight et al., 2000).

This case study is aimed to evaluate the eradication capability of entomopathogenic fungus *Isaria fumosorosea* Wize (formerly *Paecilomyces fumosoroseus* (Wize) A. H. S. Br. & G. Sm.) (Luangsa-Ardi et al., 2005) when used to protect poinsettia plants against *B. tabaci* during shipping.

Material and methods

*Insects*

The colony of *Bemisia tabaci* (biotype B) was maintained on beans (*Phaseolus vulgaris*) in
indoor air-conditioned rooms at 24±1ºC with approximate 60% relative humidity (RH) and daily photoperiod 12/12 hrs. Synchronised populations of B. tabaci nymphs were obtained after poinsettia plants (Euphorbia pulcherrima, well rooted cuttings in rockwool medium, 4-6 leaves/per plant) were infested by allowing 16-24 hrs for oviposition by B. tabaci adults and placed into a separate air-conditioned room after adults were removed from each plant. Plants were used when early L4 nymphs became the predominant developmental stage.

**Fungus**

* I. fumosorosea strain PFR 97 Apopka was used in all experiments. This pathogen was maintained as surface cultures on potato dextrose agar (PDA, DIFCO) in sterile 90 × 15-mm plastic Petri dishes. Inoculated plates were incubated at 25ºC for 10-14 days. A conidial suspension was obtained by rinsing PDA plates with 0.05% Tween 80 and before adjusting the suspension to the proper titer (1.0 × 10⁷ spores/ml). The concentration of conidia was determined using a hemocytometer (Improved Neubauer).

**Bioassays protocols**

Standard laboratory bioassay procedure involved placing one L4 nymph of B. tabaci in a drop of conidial suspension on a sterile microscope slide (30 nymphs per slide). Slides with nymphs were placed into wet chambers (sterile plastic Petri dish with moistened filter paper on the bottom) and incubated at various temperatures (12ºC-30ºC). A rating system was used to assess the degree of fungal development on the host. When assessed, each nymph was rated individually and results were expressed as mean FDI value (Fungus Development Index) (for details see Landa et al. (1994)). For “shipping like” experiments, poinsettia plants with B. tabaci populations synchronized to L4 nymphs were treated with a conidial suspension using an aerosol spray atomizer (SPRA-TOOL, Crown, Woodstock, Illinois, USA). When dry, plants were placed into air-conditioned growth chambers for 7 days. To simulate shipping like conditions various temperature regimes where applied based on shifting plants in between growth chambers adjusted to 15ºC and 24ºC. When exposed to lower temperature, plants were packed for shipping in sealed cardboard boxes, when exposed to the higher temperature, plants were removed from boxes and maintained in a photoperiod of 12/12 hrs. Various temperature regimes were applied and tested, where total period (7 days) consists of period in lower temperature (15ºC) followed with a period in higher temperature (24ºC) (e.g. temperature regime defined as 3/4 donates temperature regime when insects were held the first three days at 15ºC followed by 4 days in 24ºC). Pre-treatment manipulation with conidial suspension was provided by pre-germination (induced by shaking the conidial suspension on linear laboratory shaker for 6 hrs prior to application, 250 r.p.m.) and/or adding a nutritive supply (0.5% glucose).

**Evaluation and statistics**

Standard laboratory bioassays were assessed daily for maximum period of 7 days and results were expressed as mean FDI ±SD. Shipping-like experiments were evaluated at the end of the complete 7 day cycle. When assessed, all leaves were removed from the plants and assessed under a stereo microscope and each L4 nymph was individually rated as either healthy, emerged, dead or infected. The data were summarized as cumulative mortality – total amount of dead and infected nymphs. Mortality in the population was analysed after arcsine-square root transformation. The effect of treatments with I. fumosorosea - PFR 97 on nymphal mortality and among nymph categories was analysed using one-away analysis of variance (ANOVA) (α=0.05), followed by comparison of means using the Turkey’s highest standard deviation (HSD) mean separation test.
Results and discussion

Based on a standard laboratory bioassay, baseline data were generated that demonstrate the influence of the constant temperature (Figure 1) and fluctuating temperature regimes within 15°C and 24°C (Figure 2) on development of entomopathogenic fungus *I. fumosorosea*. Besides confirmation that *I. fumosorosea* develops significantly faster at temperatures above 20°C (developmental cycle completed between 3 days at 30°C to 7 days at 21°C), we determined that development did progress at temperatures below 20°C (Figure 1).

![Figure 1. Development of entomopathogenic fungus *Isaria fumosorosea* under different constant temperatures (standard laboratory bioassay on *B. tabaci* L4 nymphs).](image)

Furthermore, even at the lowest temperature, FDI values above 1.0 (= superficial growth on host surface) (Landa *et al.*, 1994) were recorded by day 6, which indicates the capability of this strain to parasitize the host even in constant temperatures as low as 12°C.

Important tendencies were found when we evaluated the influence of fluctuating temperature (15°C to 24°C) during a 7 day period. Principally, a significant acceleration in fungal development of fungus was observed within the first 24 hrs after the experimental chambers were moved from 15°C to 24°C.

The bioassay conducted to define influence of a fluctuating temperature regime on the efficacy of *I. fumosorosea* on populations of synchronized to L4 nymphs on poinsettia confirmed the above mentioned tendencies. Cumulative mortality in populations of L4 nymphs ranged from 7.64% (untreated control plants held in constant regime 0/7) to 98.69% on plants treated with *I. fumosorosea* held in the constant regime 0/7 (F=432.25; df=5.24; p<0.0000). Cumulative mortality induced by PFR 97 Apopka ranged from 87.7% (regime 7/0 - constant low temperature) to 98.7% (regime 0/7), however, rather high mortality was also recorded in population of *B. tabaci* on plants, which were held under both “shipping like” regimes 3/4 and 4/3: 95.7% and 93.9%, respectively. These results indicate that being exposed to low temperature during first 3 or 4 days after application doesn’t influence the efficacy (=cumulative mortality) of *I. fumosorosea* strain PFR 97 significantly. However, important differences between temperature regimes became more apparent when cumulative mortality is...
separated to its components. As to evaluation of fungus related mortality the most important category is the infected nymph, because the appearance and superficial growth of fungus on the host body usually indicates the completion of the parasitic phase of the fungal life cycle and proliferation on the dead host (equal to FDI values from 1.5 to 2.0 in standard laboratory bioassay). Compared to cumulative mortality values, relevant and significant differences become evident when particular components are assessed separately. The length of time exposed to the lower temperature reduced the outward manifestation of infection (9.64% infected in the 7/0 regime compared to 86.9% in the 0/7 regime) but the percentage rated dead when exposed to the lower temperature increased (78.01% dead in the 7/0 regime compared to 11.67% in the 0/7 regime) (Table 1).

Figure 2. Development of entomopathogenic fungus *Isaria fumosorosea* under different temperature regimes (standard laboratory bioassay on *B. tabaci* 4th instar nymphs).

The efficacy of *I. fumosorosea* is closely correlated with dose of infectious propagules. Dose response expressed as increased cumulative mortality was observed after synchronized populations of *B. tabaci* nymphs were exposed to serial concentrations ranging from $1.0 \times 10^6$ to $1.0 \times 10^8$ spores/ml (temperature regime - 3/4). Cumulative mortality in populations of *B. tabaci* L4 nymphs treated with different concentrations of conidial suspensions increased from 82.7% ($1.0 \times 10^6$/ml) to 99.5% ($1.0 \times 10^8$ spores/ml) ($F=362.62$; df=3.16; p<0.0000). Differences were observed when the components of the cumulative mortality were compared. Regardless of the fact that all treatments were exposed to identical temperature conditions, the higher dose of fungus always correlated with a higher proportion of infected nymphs. When treated with a conidial suspension $1.0 \times 10^6$/ml, the cumulative mortality (82.51%) consists of 62.05% dead and 20.43% infected nymphs, while in the population treated with $1.0 \times 10^8$ spores/ml the cumulative mortality (99.52%) consists of 32.12% dead and 67.13% infected (Table 2).
Table 1. Influence of temperature regime on efficacy of *Isaria fumosorosea* on L4 nymphs of *Bemisia tabaci* (poinsettia, 7 days after treatment, temperature regime - held at days 15ºC/ days 24ºC).

<table>
<thead>
<tr>
<th>Temperature regime</th>
<th>Alive</th>
<th>Dead</th>
<th>Infected</th>
<th>Emerged</th>
<th>Cumulative mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control - 0/7 (183.0±38.8)</td>
<td>17.0±2.5 (8.5%)</td>
<td>16.1±4.7 (7.6%)</td>
<td>0.0±0.0 (0.0%)</td>
<td>66.3±4.2 (83.8%)</td>
<td>16.1±4.7 (7.6%)</td>
</tr>
<tr>
<td>Control - 7/0 (140.2±13.2)</td>
<td>41.4±4.2 (43.6%)</td>
<td>35.3±2.7 (33.3%)</td>
<td>0.0±0.0 (0.0%)</td>
<td>28.6±3.3 (22.9%)</td>
<td>35.3±2.7 (33.3%)</td>
</tr>
<tr>
<td>PFR - 0/7 (171.2±40.7)</td>
<td>3.4±1.1 (0.4%)</td>
<td>20.0±2.6 (11.7%)</td>
<td>68.9±3.0 (87.0%)</td>
<td>6.5±3.7 (0.9%)</td>
<td>83.5±3.6 (98.7%)</td>
</tr>
<tr>
<td>PFR - 7/0 (114.0±12.9)</td>
<td>17.9±2.3 (9.5%)</td>
<td>62.1±1.7 (78.0%)</td>
<td>18.1±2.4 (9.6%)</td>
<td>9.6±1.9 (2.8%)</td>
<td>69.5±1.9 (87.7%)</td>
</tr>
<tr>
<td>PFR - 3/4 (136.6±22.8)</td>
<td>9.9±2.1 (2.9%)</td>
<td>40.6±4.6 (42.3%)</td>
<td>47.0±4.6 (53.4%)</td>
<td>6.6±3.2 (1.32%)</td>
<td>78.1±1.4 (95.7%)</td>
</tr>
<tr>
<td>PFR - 4/3 (128.0±21.5)</td>
<td>13.7±2.6 (5.6%)</td>
<td>50.2±1.6 (59.0%)</td>
<td>36.2±1.3 (34.8%)</td>
<td>3.9±3.0 (0.5%)</td>
<td>75.7±2.8 (93.9%)</td>
</tr>
</tbody>
</table>

*Means of nymphs per plant ±SD; ‡ Means of data ± SD, expressed as angular value [arcsine √ (No. of dead and infected whiteflies/ total No. of whiteflies)]. Mortality rates (%) of dead and infected whiteflies in brackets; a,b,c Means within a column followed by the same letter are not significantly different (ANOVA procedure; α=0.05; Tukey HSD test) – (capital letters represent differences among nymph categories, small letters represent differences among temperature regimes).*

The potential of pre-treatment manipulations were also tested to assess the potential to enhance efficacy of entomopathogenic fungi. Pre-germinated conidia induced slightly higher mortality (94.46%) of *B. tabaci* compared to 92.52% mortality of nymphs treated with fresh conidia. Also, when applied with the addition of 0.5% glucose both types of conidial suspension (fresh or pre-germinated conidia) induced higher mortality compared to treatments without this nutritional support (Table 3). The highest cumulative mortality (98.98%) was achieved when L4 nymphs were treated with pre-germinated conidia in a suspension that was also enriched with 0.5% glucose. Regardless of the fact that statistical analysis of these data indicates relevant differences among pre-treatment manipulations (cumulative mortality occurring in L4 nymphs varied significantly; F=630.75; df=4.20; p<0.0000), both pre-application treatments seemed to be more effective at stabilizing mortality than increasing it.

The significance of these results are important from the standpoint that we now have data to support pre-shipment treatments of ornamental plants with an insect pathogenic fungus. These treatments will, when combined with current requirements add and additional level of insurance that plants will not be shipped infested with living *B. tabaci*. The next studies will to be conducted will include similar evaluations against *B. tabaci* eggs which are known to be infected by this fungus. We will also, if additional funding and permits are secured, validate these results with reciprocal shipments of infested plants between quarantine facilities in the United States and Czech Republic.
Table 2. Influence of dose on efficacy of *Isaria fumosorosea* on L4 nymphs of *Bemisia tabaci* (poinsettia, 7 days after treatment, temperature regime 3 days/4 days - 15°C/24°C).

<table>
<thead>
<tr>
<th>Spore concentration</th>
<th>Structure of <em>B. tabaci</em> L4 nymphs population(^\text{a})</th>
<th>Alive</th>
<th>Dead</th>
<th>Infected</th>
<th>Emerged</th>
<th>Cumulative mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (78.8±9.3)(^\text{y})</td>
<td>Ba 33.0±4.3 (29.7%)</td>
<td>Ba 24.2±4.8 (16.7%)</td>
<td>Cc 0.0±0.0 (0.0%)</td>
<td>d 47.0±5.3 (53.5%)</td>
<td>Aa 24.2±4.8 (16.7%)</td>
<td>a</td>
</tr>
<tr>
<td>PFR 1.0x10^6/ml (132.0±21.8)</td>
<td>Cb 19.7±2.5 (11.4%)</td>
<td>Ba 52.0±1.8 (62.1%)</td>
<td>Aa 26.9±1.9 (20.4%)</td>
<td>Ba 14.3±3.6 (6.1%)</td>
<td>Cb 65.3±1.2 (82.5%)</td>
<td>b</td>
</tr>
<tr>
<td>PFR 1.0x10^7/ml (154.2±32.1)</td>
<td>Be 10.0±4.4 (3.0%)</td>
<td>Ba 42.4±2.7 (45.5%)</td>
<td>Ab 44.9±3.1 (49.8%)</td>
<td>Ab 7.5±2.1 (1.7%)</td>
<td>Be 77.5±1.1 (95.3%)</td>
<td>c</td>
</tr>
<tr>
<td>PFR 1.0x10^8/ml (130.6±11.2)</td>
<td>Cc 3.9±3.1 (0.5%)</td>
<td>Ba 34.6±6.0 (32.1%)</td>
<td>Bb 55.2±6.0 (67.1%)</td>
<td>Aa 0.0±0.0 (0.0%)</td>
<td>Cb 86.1±3.1 (99.5%)</td>
<td>d</td>
</tr>
</tbody>
</table>

\(^\text{y}\)Means of nymphs per plant ±SD; \(^\text{a}\)Means of data ± SD, expressed as angular value \(\text{arcsine} \sqrt{\text{No. of dead and infected whiteflies/ total No. of whiteflies}}\). Mortality rates (%) of dead and infected whiteflies in brackets; \(a,b,c\)Means within a column followed by the same letter are not significantly different (ANOVA procedure; \(\alpha=0.05\); Tukey HSD test) – (capital letters represent differences among nymph categories, small letters represent differences among spore concentrations).

Table 3. Influence of pre-treatment manipulation on efficacy of *Isaria fumosorosea* on L4 nymphs of *Bemisia tabaci* (poinsettia, 7 days after treatment, temperature regime 3 days/4 days - 15°C/24°C).

<table>
<thead>
<tr>
<th>Pre-treatment manipulation</th>
<th>Structure of <em>B. tabaci</em> L4 nymphs (^\text{z})</th>
<th>Alive</th>
<th>Dead</th>
<th>Infected</th>
<th>Emerged</th>
<th>Cumulative mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (149.4±39.2)</td>
<td>Aa 40.2±2.8 (41.6%)</td>
<td>Ba 22.1±1.2 (14.2%)</td>
<td>Bb 0.0±0.0 (0.0%)</td>
<td>Cc 41.7±2.2 (44.1%)</td>
<td>Aa 22.1±1.2 (14.2%)</td>
<td>c</td>
</tr>
<tr>
<td>PFR F (142.6±21.6)</td>
<td>Cb 10.6±1.9 (3.4%)</td>
<td>Ba 39.6±2.2 (40.6%)</td>
<td>Ba 46.1±1.7 (51.8%)</td>
<td>Ab 11.6±1.2 (4.1%)</td>
<td>Cb 74.2±1.2 (92.5%)</td>
<td>b</td>
</tr>
<tr>
<td>PFR F+G (146.6±25.3)</td>
<td>Ccd 4.7±2.9 (0.7%)</td>
<td>Ba 39.2±3.9 (39.9%)</td>
<td>Ba 49.8±3.9 (58.2%)</td>
<td>Ab 6.0±1.6 (1.1%)</td>
<td>Cc 82.4±1.8 (98.2%)</td>
<td>a</td>
</tr>
<tr>
<td>PFR PREG (182.2±65.8)</td>
<td>Cbc 7.6±2.6 (1.8%)</td>
<td>Ba 35.7±3.5 (34.0%)</td>
<td>Ba 51.1±4.0 (60.4%)</td>
<td>Ab 11.1±2.4 (3.7%)</td>
<td>Cb 76.5±2.0 (94.5%)</td>
<td>b</td>
</tr>
<tr>
<td>PFR PREG+G (141.0±47.5)</td>
<td>Cd 3.1±2.8 (0.3%)</td>
<td>Bb 25.7±5.2 (18.8%)</td>
<td>Bb 63.5±5.6 (80.1%)</td>
<td>Aa 4.8±3.4 (0.7%)</td>
<td>Cc 84.3±3.4 (99.0%)</td>
<td>a</td>
</tr>
</tbody>
</table>

\(^\text{y}\)Means of nymphs per plant ±SD; F = fresh, PREG = pre-germinated, G = glucose; \(^\text{z}\)Means of data ± SD, expressed as angular value \(\text{arcsine} \sqrt{\text{No. of dead and infected whiteflies/ total No. of whiteflies}}\). Mortality rates (%) of dead and infected whiteflies in brackets; \(a,b,c\)Means within a column followed by the same letter are not significantly different (ANOVA procedure; \(\alpha=0.05\); Tukey HSD test) – (capital letters represent differences among nymph categories, small letters represent differences among pre-treatment manipulations).
Acknowledgements

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References


Prey-Stage Preference in *Scolothrips longicornis* Priesner (Thysanoptera: Thripidae) on *Tetranychus urticae* Koch (Acari: Tetranychidae)

H. Pakyari¹, Y. Fathipour², M. Rezapanah³, K. Kamali²
¹Department of Plant Protection, Islamic Azad University, Takestan Branch, Iran, E-mail: hajar.pakyari@gmail.com; ²Department of Entomology, Faculty of Agriculture, Tarbiat Modares University, P.O. Box 14115—336; Tehran, Iran, E-mail: fathi@modares.ac.ir; ³Department of Biological Control, Iranian Research Institute of Plant Protection, Tehran, Iran, E-mail: rezapana@yahoo.com

**Abstract:** The prey-stage preference of the predatory thrips, *Scolothrips longicornis* Priesner, for the two-spotted spider mite, *Tetranychus urticae* (Koch) was studied in 24-h laboratory experiments at 26 ±2°C, 60 ±5% RH and 16:8 L:D. The results showed that adult spider mites were the most preferred stage with approximately 8 individuals being eaten per day. *S. longicornis* has no preference between the juvenile stages of the spider mite, the consumption being approximately 5 individuals per day.

**Key words:** two-spotted spider mite, predatory thrips, *Scolothrips longicornis*, *Tetranychus urticae*

**Introduction**

Spider mites (Acari: Tetranychidae) are widespread agricultural pests, which often cause severe damage to various crops (Gerlach & Sengonca, 1985). The use of fertilizer, better crop management and chemical plant protection seem to enhance their intrinsic power of increase (van de Vrie et al., 1972). Biological control is an alternative to chemical methods of plant protection. Among the natural enemies of spider mites are predaceous thrips – three thrips families (Phlaeothripidae, Aeolothripidae and Thripidae) include acarophagous species with various degree of specialization on mites. All species of the genus *Scolothrips* appear to be specialized predators of spider mites (Priesner, 1950).

*Scolothrips longicornis* Priesner is a native beneficial thrips in Iran. It is common in fields of bean, cucumber and tomato and is considered to be an important predator of numerous spider mites species. In the present study the preference of *S. longicornis* for different stages of spider mites was examined.

**Material and methods**

**Rearing and general experimental procedures**

All *S. longicornis* were taken from laboratory colonies maintained on mixed stages of *T. urticae*. Colonies had been sustained in the laboratory with field-collected individuals added periodically. Spider mites were reared on lima bean.

For experiments, leaves were placed individually on moist tissue paper in a Petri dish (60 mm diameter) with a 25-mm diameter mesh-covered hole in the lid to allow ventilation. 80 spider mites (20 eggs, 20 larvae, 20 nymphs and 20 adults) and one female *S. longicornis* (max 24 h old) were added to each leaf and the number of each stage eaten determined after
24 h. The experiments took place at laboratory condition (26 ±1°C, 60 ±5% RH, 16:8 L:D) and was replicated 10 times.

**Result**

The results of the prey-stage preference by adult females of *S. longicornis* presented with eggs, larvae, nymphs and adults of *T. urticae* as prey are illustrated in Table 1. The female predatory thrips preyed on all stage of spider mites but preferred adult mites of which about 8 individuals were consumed per day. There was no significant differences in the preference of *S. longicornis* for the juvenile stages of the spider mite.

Table 1. The mean number (± s.e.) of different stages of *T. urticae* eaten by *S. longicornis* during the 24-h experimental period.

<table>
<thead>
<tr>
<th>Prey Stage</th>
<th>Egg</th>
<th>Larva</th>
<th>Nymph</th>
<th>Adult</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number eaten</td>
<td>4.8 ± 0.29&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.7 ± 1.16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.7 ± 1.16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.9 ± 1.20&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Values followed by the same letters were not significantly different at the 5% level (LSD test).

**Discussion**

In this study we observed that adult females of *S. longicornis* are well moving predators and the earliest and/or most frequent predator of spider mites found in cucumber.

The predatory thrips was able to feed on all stages of the spider mite, but preferred adults. Presumably both the larger size of the adult spider mites (higher nutritional value) and the greater mobility (increased chances of contact) plays a role in determining this.

Studies of the prey stage preference for *T. urticae* for other spider mites predators have shown that the predatory mite *Euseius hibisci* (Acari: Phytoseiidae) had a prey consumption inversely related to prey size, with highest consumption of eggs (ca. 4 eggs per adult female per day) (Badii *et al.*, 2004), whereas adult females of the staphylinid *Oligota kashmirica benefica* (Coleoptera: Staphylinidae) mainly the immobile stages (i.e. both eggs and quiescent stages) (Shimoda *et al.*, 1997).

**References**


Predatory mites for biocontrol of Western Flower Thrips, 
*Frankliniella occidentalis* (Pergande), in cut roses

Juliette Pijnakker, Pierre Ramakers
Wageningen UR Glastuinbouw, Violierenweg 1, 2665 MV Bleiswijk, The Netherlands, E-mail: juliette.Pijnakker@wur.nl

**Abstract:** Integrated Pest Management is used on less than 15% of the cultivated rose area in The Netherlands. Control of the Western Flower thrips *Frankliniella occidentalis* is an obstacle for further expansion of IPM in this crop. Research was started on a number of generalist phytoseiids in order to enlarge the number of predator species available for rose growers. A series of phytoseiids were tested for their affinity to rose as a host plant and to greenhouse conditions as an environment. Among four species compared, *Amblyseius swirskii* and *Euseius ovalis* were found to be promising control agents for thrips.

**Keywords:** rose, thrips, *Frankliniella occidentalis*, biocontrol, integrated pest management, predator, Phytoseiidae, *Euseius ovalis*, *Amblyseius swirskii*, *Neoseiulus cucumeris*, *Amblyseius andersoni*

**Introduction**

For controlling thrips, some Dutch rose growers used to carry out monthly introductions of *Neoseiulus cucumeris* for no better reason than that this species was available and cheap. The vast majority would not even consider biocontrol. From 2003 onwards, the research stations of Naaldwijk, Aalsmeer and Boskoop have been researching a different scenario for this crop, starting from the plant-predator relationship rather than from the traditional pest-predator approach. Priority was given to finding generalist phytoseiids suitable for the “faunistic desert” that a greenhouse crop usually is. Bearing in mind that rose is a multi-year cultivation, emphasis was put on the persistence of predators’ populations rather than on short term effects of artificial introductions. Secondary to that, we intend to study to what extent these predators have a suppressing effect on which pests.

Leaf-borne phytoseiids were collected on Rosaceae both outdoors and in greenhouses and some 10 (commercial or new) species were introduced and monitored in an experimental glasshouse with full-grown roses (van der Linden, 2004; Pijnakker, 2005). The potential of 4 selected species to control Western Flower Thrips (WFT) was then studied, results of which are presented below. On demand of the committee supervising the project, only commercially available or at least near-market species were used.

**Materials and methods**

The experiment took place in 4 insect-proof greenhouses at the previous research station of Naaldwijk. *Neoseiulus cucumeris* was provided by BCP and Biobest, *Amblyseius andersoni* by Syngenta Bioline and *Amblyseius swirskii* by Koppert. The sachets of *A. swirskii* and *A. andersoni* were found to contain about 150 predators each; those of *A. cucumeris* 250 for the first producer and 900 for the second one. *Euseius ovalis* was reared in a climate box on
detached sweet pepper leaves covered with cattail pollen at the research station. Thrips were collected from flowering pot chrysanthemums.

**Experimental design**
The experiment started in March 2006. A 3½ year old rose crop cv. Abracadabra was transplanted into 4 greenhouses of 76 m² each. The plants were grown in rockwool in 7 beds 1 m wide and 7 m long. The setpoint was 20°C for the heating. The soil was covered with a wet carpet for maintaining air humidity. Supplementary light (6,000 lux) was applied during max. 20 hours a day. CO₂ was supplied during the light period at ±800 ppm. The ventilation openings were covered with insect-proof screens (0.40 × 0.40 mm mesh). The roofs were shaded with a white coating. Four treatments with bifenzate (Floramite) had been carried out 4 weeks before the experiment. At the start of the experiment, sulphur evaporators were switched off. Instead, compatible fungicides (dodemorph, bitertanol) were regularly sprayed for controlling powdery mildew. Inundative releases of *Encarsia formosa* and *Phytoseiulus persimilis* were carried out to prevent establishment of whiteflies and spider mites, respectively. 80 WFT adults were introduced weekly in each greenhouse from week 15 to week 19. In each greenhouse a different predator species was released. Introductions of *N. cucumeris*, *A. andersoni* and *A. swirskii* took place in weeks 15, 21 and 27, at a rate of 1 sachet per 2 m². Sachets are open rearing units. They are supposed to release a multiple of that number during the subsequent weeks. Since *E. ovalis* cannot be mass-reared that way, a “drizzle introduction” was used instead. The same number of release points was then used. 9,500 *E. ovalis* were released in total during the experiment against 17,100 *A. swirskii*, 17,100 *A. andersoni* and 77,900 *A. cucumeris*.

To avoid cross contamination between greenhouses, human activities (flower harvest, crop maintenance, sampling) were carried out by two different people on two different days.

**Assessments**
For assessing the thrips population, three yellow sticky traps per greenhouse were hung and replaced weekly. Samples of 105 leaves (5 leaflets each) per greenhouse were collected every six weeks. The leaves were examined under a stereo-microscope. Mobile instars of the predatory mites were counted. All nymphs and adult predatory mites were transferred into Marc André medium on a microscope slide. The slides were heated for a few days for clearing after which the specimens were identified microscopically.

**Results and discussion**
*A. swirskii*, *E. ovalis* and *A. andersoni* were found able to establish on rose crops over several generations. *N. cucumeris*, however, failed to do so. The low numbers recovered are believed to have come directly from the sachets.

*A. swirskii* and *E. ovalis* reached the highest population density (Figure 1), corresponding with the lowest numbers of thrips in those compartments (Figure 2). However, neither predator could prevent thrips from damaging petals periodically. In the compartments where *N. cucumeris* and *A. andersoni* were released, severe damage was inflicted on flower buds.

In July, the experiment went through a (for Dutch standards) hot spell. Outdoor temperatures exceeded 30°C, and the relative humidity in the greenhouses often dropped below 50%. We assume that this factor in particular accounted for the dramatic collapse of all predator populations as observed in week 31.
All predator species except *N. cucumeris* recovered without additional releases being necessary (Figure 1). The predators showing up in the *cucumeris*-compartment later were found to be *A. swirskii*. We assume that this was caused by a contamination observed in the second charge of the *cucumeris*-sachets.

The temporary release of predation pressure on the thrips larvae might have triggered the peak of the thrips flight monitored in summer (Figure 2). In this part of the interaction, again the highest predator population and the lowest thrips numbers were observed in the *swirskii*-compartment. The decline of all thrips populations observed in September might have been caused by both predation and seasonal effects.

![Figure 1. Numbers of four predatory mite species after repeated releases in spring (NB: The *cucumeris*-compartment was eventually taken over by *A. swirskii*).](image)

**Outlooks**

Apart from the specialized spider mite predators *P. persimilis* and *A. californicus*, Dutch rose growers can choose between at least 4 generalist phytoseiids available: *N. cucumeris* and *Iphiseius degenerans*, both borrowed from the vegetable scene, *A. swirskii* since early 2005 and *A. andersoni* since early 2007. The merits of phytoseiids for controlling spider mites are widely recognized. Their benefits for suppressing thrips, whiteflies or even mealybugs, however, are questionable. Some IPM growers will continue repeated inundative introductions, gradually replacing *N. cucumeris* by *A. swirskii*. A small number of pioneers will experiment with combinations of species (for example: *N. cucumeris* of *A. swirskii* in winter and *I. degenerans* in high summer), possibly cultivar depending (more or less leathery leaves, associated microclimate).

A much longer list of phytoseiid species is available for research. Wageningen UR Glastuinbouw will continue to work on both available and “new” species, in close cooperation with companies supplying natural enemies and with the Section Population Biology of Amsterdam University. Difficulties encountered in this research include:
1. complexity of the theme itself (see for example Messelink & Janssen, these proceedings)
2. accession to life material (laboratory cultures, natural sources)
3. new regulations on fauna protection, hampering releases of exotic or even native species.

Figure 2. Trends of thrips numbers on yellow sticky traps in the presence of different predatory mites.

Acknowledgements

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References

Biological activity of two strains of *Lecanicillium lecanii* (Zimmerm.) Zare & Gams to *Myzus persicae*

Lyudmila Prischepa, Ekaterina Ugnachyova
RUC “Institute of Plant Protection”, Laboratory of Microbiological Method, Minsk region, p. Priluki, Mira – 2, Belarus, E-mail: prischepa-2625@yandex.ru

**Abstract:** The pathogenicity of two strains of the entomopathogenic fungus *Lecanicillium lecanii* (Zimmerm.) Zare & Gams (ПV-1 and BL-2) to green peach aphid *Myzus persicae* Sulzer was investigated. There were no significant differences in strains effectiveness. The highest biological effect was on the 10th day after application (73% aphid mortality). The fungus productivity depended on the media and the temperature of cultivation. Malt-agar and a temperature of 26°C were optimal for cultivation of the strains. The strain BL-2 has higher spore titer than ПV-1.

**Key words:** *Lecanicillium lecanii*, *Myzus persicae*, tomatoes, productivity, biological activity

**Introduction**

The area cultivated in Belarusian glasshouses is approximately 200 ha. Aphids are widespread pests of in the glasshouse vegetable crops with green peach aphids causing significant damage to sweet peppers and tomatoes. Aphids have many natural enemies, among which entomopathogenic fungi are of great interest.

The fungus *Lecanicillium lecanii* (Zimmerm.) Zare & Gams was mentioned for the first time in 1861 in Ceylon as a scale insect parasite (Gulij et al., 1982), its use for citricola scale control in citrus plants was known (Evlahova, 1941). Subsequent studies showed that *L. lecanii* affects a wide range of pests including species of the Lepidoptera, Homoptera, Coleoptera (Evlahova, 1974), Thysanoptera, Diptera, and Hemiptera orders (Xinmin et al., 2006).

Many authors have noted a high biological activity of *L. lecanii* to aphids causing damage under greenhouse conditions (Beglyarov & Ponomaryova, 1986; Korol, 1986; Pavlyushin, 1998; Geshtovt, 2003; Ahatov & Izhevskij, 2004). The aim of our study was to determine the biological activity of two strains *L. lecanii* (ПV-1 and BL-2) to green peach aphid *Myzus persicae* Sulzer.

**Materials and methods**

*Strains productivity determination*

To evaluate the productivity of the strains of *L. lecanii* cultivations consisting of four replicates on five agar media (Malt-agar, Saburo, Chapecta, Potato-peptone agar, PDA) were examined. Fungi plating was done by dot inoculation on solid medium. To study the influence of temperature on the growth and sporulation of the strains, Petri dishes were incubated at 26°C and 30°C. The titer of the spores were determined on the 14th cultivation day. The sporulation intensity was determined by a direct spore recording in a Goryaev chamber.
**Strain cultivation**
The fungus was grown by solid-phase method on Malt-agar at 26°C (Gulij et al., 1981). Suspensions for treatments were prepared by washing off spores from the preparation. The spore concentration was determined by direct record in a Goryaev chamber.

**Biological activity determination**
Biological activity evaluation was done under greenhouse conditions. The experiments were carried out in greenhouses at the State Farm Staro-Borisov on tomato plantings cv. Dobrun. Two concentrations of fungal suspensions were used for application: 7.4×10⁷ and 14.8×10⁷ spores/ml for ΠV-1; and 8.6×10⁷ and 17.2×10⁷ spores/ml for BL-2. The leaves colonized by aphids were selected, labelled and treated once, the pest nymphs and adults were recorded. The treated leaves were put in isolators. The control treatment consisted of water only. The assay was repeated four times for each strain and control. The insect number was recorded before, on the 5th, 10th and 15th day after treatment, and biological activity was determined according to Abbott formula (Abbott, 1925).

**Results and discussion**
The productivity of the strains of *L. lecanii* depended on the media composition and on the temperature of cultivation. The experimental results are presented in Table 1. Malt-agar was the optimal medium for strains cultivation. The highest productivity was at temperature 26°C. The strain BL-2 had a higher productivity than strain ΠV-1.

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<th>ΠV-1</th>
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<tr>
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<td>Chapeka</td>
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The strains of the entomopathogenic fungus *L. lecanii* had a high biological activity to *M. persicae* during testing under greenhouse conditions (Figure 1). The treatments resulted in an average 66% mortality at 5 days, 73% mortality at 10 days and 70.5% mortality at 15 days post-inoculation. The maximum biological effect of the preparations was noticed on the 10th day after treatment. There were no significant differences between strains in terms of biological activity and there were no significant differences between the actions of the lower and higher spore concentrations.
The conidia of *L. lecanii* strains germinated rapidly on the surfaces of aphid nymphs and adults. Fungal elements were present in significant amounts on the bodies 5 days after treatment. Aphids covered by white fluffy mycelium were discovered on tomato leaves (Figure 2).

**Figure 1.** Biological activity of *Lecanicillium lecanii* strains against *Myzus persicae*.

**Figure 2.** Peach aphid nymphs infected with *L. lecanii* (5th day after treatment).
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Efficacy of Eradicoat and Eradicoat T against *Tetranychus urticae* (Koch), their toxicity to *Phytoseiulus persimilis* (Athias-Henriot) and their role in integrated pest management programs

Adam Root, Clare Sampson, Jennifer Lewis
Biological Crop Protection Ltd. Occupation Road, Wye, Ashford, Kent, TN25 5EN, E-mail: adamR@biological-crop-protection.co.uk

**Abstract:** Eradicoat and Eradicoat T are physically acting insecticides based on Maltodextrin. They control a wide range of insect pests. Trials on pepper plants resulted in control of *Tetranychus urticae* that was comparable to conventional pesticides. Although direct spray would be harmful to *Phytoseiulus persimilis* there is no residual toxic effect, allowing these predatory mites to re-colonize or be re-introduced into treated areas immediately following treatment. This makes Eradicoat and Eradicoat T very valuable tools in an IPM program.

**Key words:** Eradicoat, biopesticides, IPM, *Tetranychus urticae*, *Phytoseiulus persimilis*

**Introduction**

Eradicoat and Eradicoat T are organic, fast acting, contact insecticides that work purely by physical means. Both are formulated from plant-derived starch (Maltodextrin), plant oils and water. They are used in many crops for the control of a wide range of small pests and work exceptionally well alongside beneficial insects (Corden, 2000; Sampson, 2005, 2007).

The difference between the two formulations is relatively small, Eradicoat T has a lower percentage of Maltodextrin than Eradicoat and has an extra plant derived surfactant which aids the distribution of the starch, reduces the viscosity of the formulation and improves efficacy.

Eradicoat and Eradicoat T have a unique mode of action. When the product is applied it coats the target pest. On drying the starch contained in the product blocks the spiracles, causing death by suffocation (Corden, 2000).

In addition to causing death by suffocation, Eradicoat and Eradicoat T have also been shown to produce an adhesive or entrapment effect. In trials at BCP aphids were found stuck to leaves after an application of Eradicoat. After the solution had dried aphids could be seen struggling to free limbs that had become stuck to the leaf surface, others had their entire bodies stuck to the leaves. Pests that become stuck to surfaces are usually unable to feed and soon die (Corden, 2000).

Eradicoat and Eradicoat T are commercially available in the UK under an exemption from the Control of Pesticides Regulations due to their physical mode of action. In the Netherlands, Eradicoat has a natural product (RUB) registration. Both products are currently undergoing EU-wide registration as biopesticides.

This paper reports on the efficacy of Eradicoat and Eradicoat T against spider mite (*Tetranychus urticae* Koch) on pepper plants and their effect on the main predator of spider mite, *Phytoseiulus persimilis* (Athias-Henriot).
Materials and methods

**Efficacy against glasshouse spider mite (Tetranychus urticae)**

The efficacy study was carried out in a glasshouse environment, in Derbyshire in the United Kingdom. Pepper plants (*Capsicum annum* var. Bellboy F1) infested with glasshouse spider mites were treated with Eradicoat, Eradicoat T, spiromesifen (Oberon) and abamectin (Dynamec) and a control treatment of water. There were four replicates per treatment and each replicate consisted of ten potted pepper plants. Four applications of each treatment were made, each 1 week apart. All applications were to run off and were carried out using a Knapsack sprayer. The numbers of adult and juvenile spider mite were assessed before treatment as well as three and seven days after each treatment (DAT). Percentage control was calculated using the Henderson-Tilton formula. Assessment data were analysed using a two-way analysis of variance (ANOVA). Newman-Keuls’ multiple comparison test was then applied to separate any treatment differences that may be implied by the ANOVA TEST.

**Toxicity to Phytoseiulus persimilis**

5-cm diameter leaf discs of dwarf French bean (*Phaseolus vulgaris* var. The Prince) were mounted upper surface down onto a layer of 1.5% agar, in the base of a 5-cm diameter Petri dish. Five discs were sprayed to run off with water and five with Eradicoat T. While the spray residue was still wet, approximately ten adult *P. persimilis* adults sourced from Biological Crop Protection’s production unit were introduced to each disc. The vented Petri dish lids were put in place and the whole test arena was inverted to maintain the leaf disk and mites in their natural orientation. *P. persimilis* mortality was assessed after 24 hours. A t-test (p=0.05) was used to check the results for any statistically significant difference.

Results and discussion

**Efficacy against glasshouse spider mite (Tetranychus urticae)**

It is clear from these results that over several applications that Eradicoat and Eradicoat T performed as well as conventional chemicals in controlling adult and juvenile *T. urticae*. In fact only in the 7 DAT1 and 7 DAT4 of the adult mites were there any significant differences between the results, in both of these abamectin was superior to other treatments, and in 7 DAT4 Eradicoat T was superior to Eradicoat and spiromesifen and not significantly different from abamectin.

These results clearly indicate that Eradicoat and Eradicoat T provide control of *T. urticae* comparable to conventional pesticides.

**Toxicity to Phytoseiulus persimilis**

There was no significant difference between the mortality in the Eradicoat T treated leaf discs and the control discs. This shows that there was no toxic effect of Eradicoat or Eradicoat T on the predatory mite when exposed to the wet residue.

**Eradicoat and Integrated Pest Management**

From the results presented here it is clear that Eradicoat and Eradicoat T had good efficacy against glasshouse spider mites (*T. urticae*) while wet residues showed no direct toxicity to *P. persimilis*. It is true that due to the products’ mode of action any *P. persimilis* directly sprayed and coated with the product would be killed, however any not coated or introduced after spraying would not be affected. The physical mode of action means that any beneficial insects that are not directly coated with Eradicoat or Eradicoat T when a crop is sprayed will survive.
Figure 1. Percentage control of adult glasshouse spider mite (*Tetranychus urticae*) on pepper in a glasshouse environment after 4 treatments of several chemicals one week apart.

Figure 2. Percentage control of juvenile glasshouse spider mite (*Tetranychus urticae*) on pepper in a glasshouse environment after 4 treatments of several chemicals one week apart.
And due to the lack of residual action these surviving beneficials will then be able to re-colonize all parts of the plant immediately and help control any surviving pest. Re-introduction of beneficials is possible immediately after spraying. The result of this is that Eradicoat and Eradicoat T can be used to control pest hot-spots or correct imbalances between the numbers of pests and beneficials without upsetting an integrated pest management program. In commercial crops growers often see the first spider mites after they have built up to damaging numbers. BCP has developed an effective strategy spraying the first spider mite outbreaks with Eradicoat or Eradicoat T to reduce numbers, then immediately releasing *Phytoseiulus persimilis*.

Eradicoat and Eradicoat T are valuable IPM tools for conventional, organic and reduced residue crops. They are based on natural products and have no residues or pre-harvest interval. EU wide approval will make these products more widely available to growers across Europe.

References

Development and implementation of biological control of spider mites in Oregon nurseries

Robin Rosetta
Oregon State University, Department of Horticulture, North Willamette Research and Extension Center, 15210 NE Miley Rd., Aurora, OR 97002-954, USA, E-mail: robin.rosetta@oregonstate.edu

Abstract: A research program was developed to promote the implementation of a biological control program for management of spider mites in outdoor nurseries in Oregon. Experiments were conducted to select appropriate phytoseiid species; study mite dispersal; develop application rates, timing, and strategies; and assess factors to improve success of implementation in commercial sites. The predator Neoseiulus fallacis, proved most adapted for the program. Establishment and spider mite suppression was most successful in broadleaved shrubs, particularly planted in blocks with a continuous canopy. Augmentative releases were considered unlikely to be successful in shade tree production.

Key words: biological control, nurseries, Neoseiulus fallacis

Introduction

In 1994 a Research and Extension program was established to promote the use of integrated pest management in the greenhouse and nursery industry in Oregon. A key focus of this program included designing research and implementation of biological control targeting key pests in this industry. Development of a biological control program for spider mites (Acarina: Tetranychidae) was deemed a high priority for several reasons including: the status of spider mites as economic pests in greenhouse, field, and container nursery production; mite outbreaks were primarily controlled by the use of synthetic miticides in nurseries; and there was concurrent research in Oregon investigating augmentative releases of predatory mites in mint, hops, and strawberries. A nice body of research has been published on this effort to investigate the biological control of spider mites in outdoor nurseries in the Pacific Northwest (Pratt, 1999; Jung & Croft, 2000; Pratt & Croft, 2000a; Pratt & Croft, 2000b; Pratt et al., 2002). The purpose of this report is to provide a brief summary of complementary research to enhance Extension efforts directed at implementation of biological control of spider mites in Oregon nurseries. The experiments were conducted to gain information regarding selection of appropriate phytoseiid species; application rates, timing, and mite dispersal; and management related factors that might hinder or improve success of augmentative releases in commercial nursery sites.

Material and methods

Investigation of phytoseiid mite species for augmentation in nurseries

A series of experiments were conducted to evaluate the potential for spider mite management by various phytoseiid mite species in augmentative releases in nurseries. In 1995 releases of Neoseiulus californicus, N. fallacis and Galendromus occidentalis occurred in one year grafted maple, Acer x freemanyii ‘Autumn Blaze’, and one year grafted linden, Tilia cordata
‘Greenspire’ at three commercial nurseries. *N. fallacis* was released in one year old *Viburnum opulus* ‘Newport’ in two nurseries and sampled in 1995 and 1996 to determine overwintering ability of this mite. In 1996 *N. fallacis* with supplemental twospotted mites, and *N. californicus* and *G. occidentalis* with or without supplemental twospotted mites were applied to maple and lindens in three nursery sites. Plots were monitored weekly prior to and after the release of predators.

**Investigation of *N. fallacis* application rates, timing and mite dispersal**

In 1997 we investigated application rates, timing, and dispersal of *N. fallacis* in field planted shade trees and container shrubs. At each of two nursery sites, a single row of ‘Greenspire’ Linden was chosen and divided into 25 plots of nine trees each. Predator mites were released either once or twice per plot and on either every tree or every third tree. In the shrubs, 15 plots were established in a block of *Spiraea japonica* ‘Shirobana’. *N. fallacis* was released either every fourth plant per plot or every eighth plant per plot.

In 1998 two rates of release for *N. fallacis* were evaluated in blocks of *Skimmia japonica* (32,388 mites/ha and 16,194/ha); and in *Spiraea japonica* ‘Shirobana’ (6,073/ha and 12,146/ha). Mites were released in two locations along one edge of each release plot, with the application evenly split between these two plants. Within each test plot, individual plants were flagged, along the perimeter and in the middle of each plot. Three leaves from flagged plants were sampled each week for mites. In *Thuja occidentalis* ‘Smaragd’ two rates/release strategies were evaluated: a high rate (100 mites released/plant, release on each plant per plot) and a low rate (100 mites released/plant, release on every other plant per plot). Sampling consisted of taking four 4" long twig samples from the second and third plants in each plot. An alcohol extraction was performed to obtain counts of prey and predators.

**Field implementation in commercial nurseries**

Lastly we worked with eight nursery cooperators in 1999 to develop monitoring programs, compatible chemical lists, release rates, and supplier options. Nurseries were visited every three weeks to monitor progress of the scouting and release program.

**Results and discussion**

**Investigation of phytoseiid mite species for augmentation in nurseries**

No predatory mites were found in sampling prior to releases in the research plots. It was found that predator mites established better on ‘Greenspire’ Linden than on ‘Autumn Blaze’ Maple. Addition of supplemental twospotted mites at the time of release was not found to improve establishment of predator mites. *N. fallacis* and *N. californicus* established better than did *G. occidentalis* in most situations. Results were variable and twospotted mite populations were not suppressed by the predator mites. Where treatment effects existed, they were most pronounced in the ‘Greenspire’ Linden, and the most effective predators were *N. californicus* and *N. fallacis*. Adult *N. fallacis* were found in 1996 sampling of the field-planted *Viburnum* ‘Newport’ 1995 release plots. Twospotted mite numbers in the release area were suppressed in comparison to areas of the plot where *N. fallacis* was not present. The most abundant arthropod predators were ladybeetles: *Stethorus* sp., *Hippodamia convergens*, and *Harmonia axyridis*. Minute pirate bugs, *Orius* sp., were first noted in the middle of August in one Linden plot and their numbers quickly increased until they were dispersed throughout the planting. They were observed feeding on *N. fallacis* in treated plots. Other predators found included green lacewings (*Chrysopa* spp.) and spiders of several species (Bell & Rosetta, 1997; Rosetta & Bell, 1998).
Investigation of *N. fallacis* application timing and mite dispersal

Results in 1997 in the shade trees show releases of *N. fallacis* on every tree to be more effective at establishing populations than releases on every third tree. No significant reduction in twospotted mites was seen due to any *N. fallacis* treatment. However, it was consistently observed that species of *Orius* and *Stethorus* gave significant, though not complete, control of twospotted mites. In the shrubs, twospotted mite numbers were reduced in plots where both the low and high rates of *N. fallacis* were released compared to control plots. Movement of *N. fallacis* through study plots was observed to be rapid following release (Rosetta & Bell, 1998).

In the 1998 *Skimmia* trials, spider mite numbers increased rapidly in all plots following the release on June 11 in the first nursery site and movement of the predators from the release site was slow. *N. fallacis* provided localized control around the release site (two to three plants away) but movement within the disjointed canopy of the *Skimmia* block did not occur very rapidly. This may be due to the lower post-dispersal survival rates on gravel substrates of dispersing mites (Jung & Croft, 2000). This may be also due to the restricted air movement in the shadehouse where the plants were located. A second release, on July 1, seemed to result in somewhat better establishment, and predators were subsequently found to move across plots from the release site. However, spider mite numbers remained high until the last week of August, when they declined rapidly. This decline coincided with a more generalized distribution of *N. fallacis* including invasion of the control plots. In the second site, following the release on May 21, spider mite numbers increased modestly following releases. For the new few weeks, *N. fallacis* were found only sporadically in the plots. Spider mite numbers rapidly declined to zero around the fourth week of June, and remained there for nearly two months. This decline was not correlated with an increase in numbers of *N. fallacis*, which remained elusive. The entire plot, including controls, was nearly free of spider mites (and predators) during this two month period. Adjacent hoop houses, which contained the same plant material and were managed with regular miticide applications, had very high populations of spider mites during this time.

In *Thuja*, *N. fallacis* established fairly well and increased in number and dispersal, invading the nearby control plots. Sampling the adjacent row indicated that they were moving between rows as well as down the release rows. Samples for the control data were subsequently taken from plants three rows away. Predators were also found in these plants after a few weeks. Spider mite numbers continued to increase, however, and the grower eventually applied a miticide, terminating the trial.

Field implementation in commercial nurseries

In our work with the commercial nurseries in 1999, we found a number of management-related challenges hindering success of predatory mite implementation: missed thresholds; inadequate within nursery communication; incomplete employee training; lack of written records; multiple pest pressures and chemical incompatibility; inconsistent quality control from various suppliers; and management concerns with costs of biological control versus chemical control. Many of the cooperators did experience success. Most of the nurseries initiated a scouting and record keeping program and gained confidence to experiment with and implement biological control. At many sites, releases appeared successful with complete control of spider mites with no apparent damage throughout the season (several reported improved plant quality). Several of the growers were able to eliminate miticide applications altogether, while some reduced the number of applications (Bell & Rosetta, 1999).

Fully integrating IPM programs has enhanced adoption of additional biological control programs. One nursery increased utilization of a soil-incorporated insecticide and periodic
applications of entomopathogenic nematodes to reduce root weevil larvae, thereby reducing broad spectrum foliar adulticide applications and allowing releases of predatory mites for spider mite management. A cut flower rose grower altered his pest management program to include aphid parasites and incorporated more insect growth regulators in order to preserve releases of predatory mites.

At this time in 2007, several of the original cooperators have continued the use of *N. fallacis* and more nurseries are incorporating applications into their programs. One of our largest container nurseries relies primarily on inoculative releases of *N. fallacis* for spider mites when they occur on broadleaved and herbaceous plants. Many of the nurseries currently using biological control have expressed an interest in expanding its use at their sites. The potential for increased adoption looks promising and remains a focus of current IPM programs.

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**References**


Developments in the use of predatory mites for biological pest control

Maurice W. Sabelis, Arne Janssen, Izabela Lesna, Nayanie S. Aratchige, Maria Nomikou, Paul C.J. van Rijn

Section Population Biology, Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Kruislaan 320, 1098 SM Amsterdam, The Netherlands, E-mail: sabelis@science.uva.nl

Abstract: Predatory mites (Acari: Phytoseiidae, but now also Laelapidae) have gained momentum as agents for successful biocontrol of plant pests. The time has gone where they were mainly considered for the control of spider mites. Various new predatory mite species have been identified for the control of other groups of pests, either plant-feeding insects or mites other than spider mites, feeding on either above-ground or below-ground plant parts and feeding either concealed in plant structures or exposed on a leaf. However, do we really understand why these predatory mites are so effective? In this article we review the underlying mechanisms and generate new questions, based on case studies of our own research on biocontrol of thrips, whiteflies, bulb mites and eriophyid mites with the use of predatory mites. Finally, we ‘wrap up’ by providing a brief ecological and phylogenetic perspective on predatory mites and their use in biocontrol.

Introduction

Plant-inhabiting predatory mites (Acari: Phytoseiidae) have proven to be successful agents for biocontrol of plant-feeding mites, such as spider mites (Acari: Tetranychidae) (Helle & Sabelis, 1985ab). This success is not so much due to their per capita predation rate, because there are other groups of natural enemies of spider mites with much higher predation rates (Helle & Sabelis, 1985b). The major advantage of using predatory mites stems from their fast numerical response to the density of the target pest and their ability to utilise alternative foods or other prey in absence of (or in addition to) the target pest. Moreover, predatory mites tend to be strongly arrested in leaf areas with their preferred spider mite as prey (e.g. Sabelis et al., 2007).

In the last 20 years some remarkable developments have taken place in the use of predatory mites. Not only has the number of phytoseiid mite species used for biological control increased substantially, but also predatory mites of other families (e.g. Laelapidae) are now also used or being considered for biological pest control. Moreover, predatory mites are not only used to control spider mites, but also other groups of plant feeding mites, such as brevipalpid, eriophyid, tarsonemid and acarid mites, and even plant feeding insects, such as thrips and whiteflies. An authoritative review of these developments is recently published by Gerson and Weintraub (2007) and this is why we refrain from providing an exhaustive review here. Instead, our aim is to highlight some of these developments and to review our insight in the mechanisms underlying successful application of predatory mites in biological control. First, we consider predatory mites selected for the control of insects that have a short vulnerable stage. Second, we focus on predatory mites controlling mites that attack below-ground parts of plants. Third, we provide new insights in how predatory mites can be used to control mites that find refuge and feeding sites within the narrow confines of plant structures. Finally, we briefly mention some other developments and pose questions for future research.
on the mechanisms driving successful biological control with predatory mites.

**Controlling insects that have a short vulnerable stage**

Although feeding on insects had been reported as early as in the sixties (e.g. Swirski *et al.*, 1967), predatory mites have not been considered as agents for biological control of insect pests for decennia thereafter. Biological control in those times was based on the idea that candidate enemies should be specific for the insect pest. Parasitoids were favoured because they showed great potential for host specificity unlike predators that are usually generalists. Moreover, the idea was that predators are usually larger than their prey. So why should tiny predatory mites be considered for control of pests, involving insects that are usually larger? Against these mainstream thoughts, Pierre Ramakers pioneered an innovative approach whereby predatory mites (*Neoseiulus barkeri* Hughes, *N. cucumeris* Oudemans), originally found in association with thrips insect larvae in the greenhouse, were mass-reared on astigmatic mites and then released in sweet pepper and cucumber crops to combat *Thrips tabaci* (Ramakers, 1980, 1983, 1988; Ramakers *et al*., 1989). This method was later tested and adopted in other countries in the west-palaearctic region (Gillespie, 1989; Hansen, 1989). The same predatory mites also showed efficacy against western flower thrips, *Frankliniella occidentalis*, a newly emerging greenhouse pest. However, there was a need to improve thrips control early in the year (i.e. February-March), when *N. cucumeris* and *N. barkeri* are still in diapause. Out of 6 candidate phytoseiid species, *Iphiseius degenerans* (Berlese) was selected because this predator is diapause-free, resists low humidities relatively well and can feed on pollen as alternative food (van Houten *et al*., 1995).

Whereas the biocontrol method was shown to work and was already widely applied in practice, an understanding of why it worked emerged at a much slower pace. First, it was found that the predatory mites used for thrips control only attack thrips larvae and that their attack success rapidly drops with the age of the thrips larvae, the rate of the decline depending on the phytoseiid species (Bakker & Sabelis, 1989; van Houten *et al*., 1995). Given the apparent success in thrips biocontrol, the question arose how these predators become abundant enough to exert control over a pest insect with a rather short phase of vulnerability to predation. Is the density of young thrips larvae high enough to trigger a numerical response of the predatory mites? Are the numbers of predators released so high that control is achieved via the functional response of the predatory mites to the density of young thrips larvae? The answer was obtained by a combination of modelling and experiments at the individual and population level (van Rijn, 2002; van Rijn *et al*., 2002). It was shown that the initial predator-to-prey ratio has to be quite high in crops such as male sterile cucumber, but that inoculative rather than inundative releases suffice in crops such a sweet pepper which provide a continuous supply of pollen as alternative food for the predators (Sabelis & van Rijn, 1997). Pollen of sweet pepper flowers or supply of cattail pollen appear to boost the population of *I. degenerans* to an extent that effective thrips control can be achieved (van Rijn *et al*., 1999). Moreover, even though western flower thrips larvae and adults also consume pollen, it was shown that *I. degenerans* can monopolise the exploitation of pollen provided it is not distributed homogeneously over the crop, but available only at small sites on some, but not all leaves (van Rijn *et al*., 2002). These predatory mites partially aggregate around pollen sites, leaving thrips little chance to eat pollen and stay alive, whereas they also forage for thrips larvae elsewhere on the plant. Unfortunately, there is still no economically feasible method to supply adequate pollen in crops that lack a natural supply of this alternative food, leaving this as a problem to be solved in the future.

Given the success in using predatory mites for thrips control, the obvious next question
was whether this type of predators could also be used to combat other insect pests. The tobacco whitefly, *Bemisia tabaci*, was chosen as a test case (Nomikou, 2003), because parasitoids gave unsatisfactory control and because some species of predatory mites were known to feed on whiteflies (Swirskii *et al.*, 1967). Exploration for predatory mites associated with whitefly infestations in unsprayed cotton fields and wild plants were carried out in Jordan and Israel. Based on their capacity for population increase on a diet of whiteflies and their ability to feed on pollen, two candidate species, *Amblyseius swirskii* Athias-Henriot and *Euseius scutalis* (Athias-Henriot), were selected (Nomikou *et al.*, 2001; Nomikou *et al.*, 2003a). These predators can feed on all immature stages, but are especially successful in attacking eggs and first instar larvae (crawlers) of the tobacco whitefly and in reproducing on a diet of these whitefly stages (Nomikou *et al.*, 2004). Population experiments in small cages showed successful control of tobacco whiteflies by each of the two predatory mite species, provided there was a supply of pollen as alternative food (Nomikou *et al.*, 2002). Successful whitefly control was also obtained in large-scale experiments with *A. swirskii* on sweet pepper and cucumber in greenhouses (Bolckmans *et al.*, 2005). The predatory mite *A. swirskii* is now commercially available for thrips and whitefly control in sweet pepper and cucumber (e.g. Koppert Biological Systems). In 2007 it has been applied on more than 5,000 ha of greenhouses in the Mediterranean area (Bolckmans, pers. comm.).

As for the case of thrips control, understanding why predatory mites, like *A. swirskii*, are so successful in controlling whiteflies, comes at a lower pace. Clearly, pollen as alternative food plays a crucial role in building up a large population of predatory mites in advance of whitefly incidence. However, adult whiteflies can learn to avoid plants occupied with predatory mites and whiteflies (Nomikou *et al.*, 2003b). In that case, whiteflies may escape in space by selecting plants void of predatory mites for oviposition. Thus, successful control probably requires a homogeneous build-up of predatory mite populations on all plants in the crop. Assessing the spatial dynamics of whitefly and predatory mites remains an important task for the future, however.

Another question emerging is whether a single predator, like *A. swirskii*, can be used to control whiteflies, as well as thrips and perhaps also broad mites. Control of multiple pests by a single predator is challenging because it requires adequate switching behaviour of the predator in response to absolute and relative densities of each of the pests. Moreover, it has to be economically attractive for the mass producer of natural enemies. If this all comes true, then selection criteria for candidate biocontrol agents have considerably changed since the eighties of the previous century.

**Controlling mites that attack plants below-ground**

Control of below-ground plant pests with predatory mites has received little attention and there are no published criteria for desired traits of biocontrol agents in the soil. The soil harbours much more spatial heterogeneity than a plant. Hence, it may require specific abilities for predatory mites to control a soil pest. The dense structure of the soil imposes a major hurdle. Predatory mites cannot dig their way through the soil. Size permitting, they have to move between soil particles, decaying organic matter and plant roots. The soil represents a labyrinth within which prey, especially when smaller than their predators, may take advantage of the fine porous structure to escape from predation. In addition, soil density increases with depth, thereby making it less accessible and creating refuges for small prey. The existence of such refuges for prey is known to stabilise predator-prey dynamics, but it will also allow a larger size of the prey population, implying more damage to the plants. The simple-minded conclusion would therefore be that biocontrol in the soil is less likely to be successful than on
above-ground plant parts. However, this conclusion may not hold for at least three reasons. Firstly, pest arthropods are unlikely to stay in the refuge forever. This is because as they deplete their resources, they have to move to other refuge sites, thereby risking death by predation. Moreover, as their size changes during development, they have to move out of their microspace refuge at a risk of being eaten because of limited spatial dimensions in the refuge. Secondly, soil structure in the rhizosphere is influenced by the dynamics of plant roots and other associated organisms. In this soil area influenced by root growth, predatory mites may have better access to deeper soil layers. Thirdly, there is great diversity in size among species of predatory soil mites, so that there might be some species small enough to reach below-ground plant pests.

Possibilities for using predatory mites to control below-ground plant pests have been investigated in lily bulbs in The Netherlands, a crop that incurs considerable damage from the bulb mite, *Rhizoglyphus robini* Claparède (Lesna, 1998). This crop is a convenient choice for initiating such a study because lily bulb cultivation occurs partly above-ground and partly below-ground, thus motivating a step-wise approach by first testing candidate predatory mites on bulbs without soil and then testing them on bulbs embedded in different types of substrate (vermiculite, peat, sandy soil). Above-ground, lily bulbs are propagated from bulb scales that are obtained by decomposing bulbs. The conditions during this propagation phase (9-12 weeks on trays with vermiculite in storage rooms at 22°C and very high humidity) are conducive to outbreaks of bulb mites. Subsequently, lily bulbs are grown for 3 years below-ground in the field (interrupted by cold storage during winter) and thereafter part of them are planted in greenhouses for flower production. Climatic conditions during flower production in the greenhouse are also conducive to pest population growth. In the field, where temperature is usually lower (i.e. in The Netherlands, highlands of Taiwan and Japan), pest outbreaks are less frequent and less severe, but still of economic importance.

To reduce or prevent pest and disease outbreaks in the propagation phase, lily bulbs are subject to hot water treatment (2 hours submergence in water of 39-40°C) and fungicide dips. These treatments decimate the population of bulb mites, but frequently do not eliminate them completely because some individuals may hide in so-called feeding chambers in the bulb. Moreover, predatory mites usually forage on the outer parts of the bulbs and are therefore exposed to these pest control treatments to an extent that they cannot survive at all. Hence, the few bulb mites surviving treatment can grow exponentially once they experience the enemy-free space and the favourable climatic conditions in the storage rooms.

Predatory mites have the advantage of being mobile and of a size similar to that of bulb mites, thereby allowing them to reach the sites where bulb mites hide between the scales of a lily bulb. Exploration for predatory mites was carried out by collecting bulb-mite infested bulbs from lily fields in The Netherlands, Taiwan and Japan, three countries with an intensive flower bulb industry. The laelapid predatory mite, *Hypoaspis aculeifer* (Canestrini), turned out to be the most promising among 8 different species found (Lesna *et al.*, 1995). This was because (1) it was found most frequent and abundant in association with bulb mites in The Netherlands and Taiwan, (2) it feeds and reproduces on a diet consisting of bulb mites, (3) it had the highest and least variable capacity to suppress small bulb mite populations in a small jar with intact or decomposed bulbs without a substrate and also with a substrate consisting of vermiculite or peat.

*H. aculeifer* was subsequently tested for its capacity to control bulb mites under conditions prevailing during bulb propagation (Lesna *et al.*, 1996). This was done by scaling up from scales of a few bulbs in small jars to scales of many bulbs in 40 liter boxes with vermiculite in a plastic bag, as is growers’ practice. Also at these spatial scales, *H. aculeifer* suppressed the bulb mites to extremely low levels, sometimes even eradicating them.
completely. These experiments together showed that *H. aculeifer* is a suitable predator to control bulb mites in the lily bulb propagation phase.

Whether the same predator is also capable of controlling bulb mites in cultivation phases involving intact bulbs, was investigated subsequently (Lesna *et al.*, 1996). These showed that intact bulbs provide more opportunity to hide from predators than bulbs decomposed into scales. Nevertheless, prey suppression was still considerable and the refuge effect probably also led to more prey and thereby more food for the predators, which ultimately resulted in larger predator populations and good control. These results prompted biocontrol tests in the even more complex environment of the soil in a greenhouse or in the field.

In greenhouses with peat soil *H. aculeifer* suppressed bulb mites to levels similar to observed in the lab on intact bulbs and also within a similar span of time (Lesna *et al.*, 2000). However, there was an effect of soil type on pest suppression: bulb mites were suppressed to a lesser degree in sandy soil, than in peat soil. Sandy soil is more compact and therefore possibly less accessible to predatory mites than peat soil. However, even in sandy soil, control was sufficient to warrant biocontrol tests on sandy soils in the field.

Field experiments in sandy soil showed continued growth of bulb mites in absence of predators, but a more than 10-fold reduction of bulb mites (as well as a more than 10-fold increase of predators) over a period of 3-4 months in the biocontrol treatment. As in the greenhouse with sandy soil, bulb mites were not completely eliminated from the lily bulbs, but remained at acceptably low levels.

In conclusion, the above approach to find biological control agents of bulb mites in lilies has led to a single candidate co-occurring with the target pest in the field: *H. aculeifer*. This predatory mite was successful in controlling bulb mites during the various cultivation phases and spatial scales used in lily bulb production (Lesna *et al.*, 1995, 1996, 2000). In going from the laboratory, to storage room, then to the greenhouse and finally to the field, the degree of spatial heterogeneity was gradually increased and this led to a decreased, yet still significant impact on the population density of bulb mites. Among the most important factors increasing spatial heterogeneity were bulb structure (decomposed vs. intact) and type of soil (peat vs. sand). One of the authors (Lesna, unpublished data) observed that *H. aculeifer* females can move through peat (and to a lesser extent also through sand) towards a bulb-mite-infested lily bulb buried in the soil and that these females show remarkable behaviour (e.g. stretching of legs, appressing the soma against the substrate) when moving in between bulb scales or bulblets.

After the experiments on bulb mite biocontrol were completed, Koppert Biological Systems developed mass rearing methods for *H. aculeifer* and – together with the Bulb Research Center in Lisse and the University of Amsterdam – they carried out predator releases in storage rooms at 6 lily farms in The Netherlands, all resulting in a pronounced decrease in bulb mite incidence (Conijn *et al.*, 1997). Because hot water treatment is the only available measure to control nematodes and fungicide dips – known to kill predatory mites – are often required too, *H. aculeifer* needs to be mass-reared and released directly after these treatments of the bulbs have been applied. This offers a simple method to prevent bulb mite pest outbreaks in storage rooms of lily bulbs. Application of this method is still restricted, however, to a small number of lily growers, mainly because bulb growers appear conservative with respect to plant protection measures. Nevertheless, Koppert Biological Systems continued to make *H. aculeifer* commercially available, because this predator appeared to be capable of controlling various other pests in the soil (thrips pupae, sciarid fly larvae).
Controlling mites that seek refuge in plant structures

Eriophyoid mites are among the smallest arthropods on Earth (Lindquist et al., 1996). Their worm-like body has a cross-section diameter of c. 50 micrometer, which is at least five times smaller than that of phytoseiid mites, one of their most significant predators (Sabelis, 1996). This minute size of the eriophyoid mite is the key to their ecological success. It enables them to reach places small enough to be free of predators (Sabelis, 1996; Sabelis & Bruin, 1996). Moreover, it allowed them to develop a plant-parasitic life-style quite different from other herbivorous arthropods (Lindquist et al., 1996). Many eriophyoids live in plant galls they induce, but the ones of interest here have a vagrant life-style, in that they frequently change feeding sites that vary in the degree of protection against predators. In agricultural crops this type of eriophyoid mites may easily reach pest status when predatory mites are lacking (Lindquist et al., 1996). Examples are Aceria tulipae on tulip bulbs, Aceria guerreronis on coconut palms and Aculops lycopersici on tomato plants. Chemical control is also bound to be less effective because eriophyoid mites may feed under protective structures of a plant. Hence, biological control with predatory mites is an option. However, several attempts to apply this method of control have failed and there are very few known cases of successful biological control (Lindquist et al., 1996). We will argue that this is not so much due to an inadequate functional and numerical response of phytoseiid predators to the density of eriophyoid mites. It is also not due to the absence of phytoseiid species that have a preference for eriophyoid mites as prey. We suspect that this is due to a lack of understanding on how host plants respond to attack by eriophyoid mites, and thereby promote the effectiveness of phytoseiid predators. Once we understand which predator species can take advantage of herbivore-induced changes in host plants, perspectives for biocontrol of eriophyoid mites may increase.

As an example, consider tulip bulbs under attack by Aceria tulipae, an eriophyd mite so tiny that it can move in between the scales of the bulbs (Conijn et al., 1996). Herbivory induces these bulbs to modify their internal structure. The resulting changes in distance between bulb scales are microscopic, yet sufficient to allow the phytoseiid predator Neoseiulus cucumeris to enter the interior space of the bulb. The consequence of this plant ‘behaviour’ is dramatic: predators clear the inside of the bulb from herbivores, which would otherwise be eaten from within. The crucial changes in bulb morphology enabling predator access are controlled by ethylene, a plant hormone released upon herbivore attack (Lesna et al., 2005). This plant hormone simultaneously induces the release of plant volatiles that attract predatory mites. Changes in attractiveness and accessibility of bulbs were demonstrated by a combination of chemical analysis (Aratchige, 2007), olfactometry (Aratchige et al., 2004) and experiments on predator-prey dynamics in which the effect of ethylene was either promoted or blocked (Lesna, Aratchige, Sabelis, Conijn, in prep.).

As another example, consider the coconut mite, Aceria guerreronis (Aratchige, 2007; Aratchige et al., 2007). It lives under the perianth of the fruit of the coconut. The perianth of the nut tightly covers the meristematic zone of the female flower and the developing nut thereafter. The edge of the perianth is so closely appressed to the fruit that it leaves little space for any mite to enter. Due to its small size, the coconut mite, however, is able to creep under the perianth. However, some predators can move under the perianth of the coconuts and attack the coconut mite. In Sri Lanka, the phytoseiid mite Neoseiulus baraki is the most common predatory mite that is found in association with the coconut mite. This predator is c. 3 times larger than the coconut mite. Nevertheless, taking this predator’s flat body and elongated idiosoma with short distal setae into account, it is – relative to many other phytoseiid mites – better able to reach the narrow space under the perianth of infested nuts.
On uninfested nuts, however, they are hardly ever observed under the perianth. Prompted by the work on the accessibility of tulip bulbs to predatory mites, as mentioned above, it was hypothesised that the nuts change their morphology in response to damage by eriophyoid mites and as a result allow predatory mites to enter under the perianth of infested nuts. This was tested in an experiment where we measured the distance between the perianth and the coconut fruit surface in 3 cultivars that are cultivated extensively in Sri Lanka (Aratchige et al., 2007). In uninfested nuts, this distance was large enough for the coconut mite to creep under the perianth, yet too small for the predator. However, when the nuts were infested by coconut mites, the perianth-fruit distance increased to such an extent that the predatory mites could also move under the perianth.

The lessons from analysing tulip bulb responses to eriophyoid mites may not only carry over to coconuts, but they may also apply to host plants protected by dense covers of (glandular) hairs. For example, glandular hairs on tomato are a very effective defence against many herbivorous mites (Chatzivasileiadis & Sabelis, 1997, 1998; Chatzivasileiadis et al., 1999, 2001), but they also hinder predatory mites (van Haren et al., 1987). Eriophyoid mites, such as Aculops lycopersici, are so small that they can move in between the glandular hairs without being affected by glandular hairs and at least some predators. Aculops lycopersici is currently an important pest in tomato crops and the use of phytoseiid predators for their biological control has failed so far. We are currently investigating whether tomato plants can drop or otherwise alter their glandular hairs in response to attack by A. lycopersici and whether these changes positively affect the access to these herbivores for some species of phytoseiid predators.

**Eco-phylogenetic perspectives and implications for biocontrol**

Each of the three examples on developments in biocontrol with predatory mites demonstrate that certain predator species do better than others given the environment within which they have to forage for prey. One may therefore ask which traits determine the suitability of these predator species. This requires a broader perspective on the phylogeny, functional morphology and ecology of taxa of predatory mites associated with plants. The debate on these traits is still pretty much in its infancy and there is much room for generating and testing new hypotheses. Below, we provide a critical and brief review of the state-of-the-art in the hope that others will be challenged to refine and define hypotheses and design critical tests. The ultimate aim is to identify potential biocontrol agents more readily among the bewildering diversity of predatory mites, living in various microhabitats (leaves, soil, roots, etc.).

What morphology-based systematics and phylogeny taught us, is that setal patterns on the soma really matter to species classification of predatory mites among the Mesostigmata and that there is a marked reduction in setal positions going from soil-inhabiting taxa (e.g. Laelapidae) to plant-inhabiting taxa (e.g. Phytoseiidae). Moreover, setae do not only differ in position, but also in length. However, what virtually all setae have in common, is that they point backwards when projected on the body mid-axis. Since mites are designed to have no eyes and to walk forwards (most of the time), they may get stuck to elements in their direct environment. In this respect setae pointing backwards represent a convenient trait for two reasons: (1) they assist in sensing sticky elements via mechanoreceptors present at their base, and (2) they minimise contact with the sticky element. Sabelis and Bakker (1992) proposed that setal patterns and morphologies (scaled to soma size) reflect adaptations to a sticky, direct environment. They proposed that the degree of protection from getting stuck can be quantified by projecting setae from longitudinal rows on body flanks and mid-dorsum on the body mid-
axis. The setal projection index expresses which proportion of the body axis is protected. In the soil the risk of getting stuck comes from all directions due to the granular three dimensional structure (with stickiness mainly coming from films of water surrounding the soil particles), but on plants the basic structure is two-dimensional. This is why the dramatic reductions in setal positions observed in plant-inhabiting taxa are consistent with the protection hypothesis of Sabelis and Bakker (1992; see also Sabelis et al., 1994). Various plant species have leaf hairs in such dense masses, that the risk of getting stuck comes at the body flanks, not at the mid-dorsum. Plant-inhabiting taxa finding their prey in these environments require a high protection index for the lateral longitudinal rows of setae, but not for the mid-dorsal rows. The spider mites (Acari: Tetranychidae) not only evolved a remarkable modification of the gnathosoma and its appendages that allowed them to feed on plants, but they also evolved an ability to produce silk. They use silk not only for attachment to the leaf surface, but also to build shelters that – among other possible functions – protect against predators from plant-inhabiting taxa. These shelters create a three-dimensional and sticky environment in which not only the spider mites themselves require adequate protection, but also the predatory mites that aim to feed on the spider mites. The ultimate form of shelter is offered by the complex and chaotically structured, yet compact webs of spider mites in the genus *Tetranychus*. Sabelis and Bakker (1992) showed that plant-inhabiting taxa of predatory mites feeding on spider mites in the genus *Tetranychus* share a high protection index along mid-dorsal and side-dorsal rows of setae, so as to obtain three-dimensional protection. The setae in these taxa (e.g. *Phytoseiulus persimilis* Athias-Henriot, *P. longipes*, *P. macropilis*) serve as a wedge to keep away the sticky silk from the soma of the predatory mites (and spider mites alike) – provided they walk forward. Saito (1983; see also his chapter in Helle & Sabelis, 1985) provided a very thoughtful classification of the different ways in with tetranychid mites utilize silk to produce shelter-like webs. This classification of spider mites offers the best available starting point to test for adaptations in setal patterns of plant-inhabiting taxa of predatory mites. There is also a need to classify leaf hair structure and patterns to test the protection hypothesis (e.g. Kreiter et al., 2002, 2003). In addition – and this is why the example on biocontrol of eriophyid mites, discussed in this article, is so important – plant morphology is not constant, but dynamic. In response to herbivory plants may undergo morphological changes that in turn may offer new chances of finding prey, that are otherwise inaccessible to plant-inhabiting predatory mites.

McMurtry and Croft (1997) used the classification of web-types provided by Saito (1983) and of setal patterns provided by Sabelis and Bakker (1992) and Sabelis et al. (1994) to make a distinction between two broad classes of Phytoseiidae: those that can enter complex silken webs (their Type I and II predators) and those that are severely hindered by those webs (their Type III and IV predators). The first class was split in specialists of spider mites with complex silken webs (Type I) and generalists (Type II). The second class was also split – and this was their major contribution – in two groups: one of pollen specialists that also prey on plant arthropods (Type III), and one that are more specialised to prey on plant arthropods than to feed on pollen (Type IV). This distinction was based on morphological features, i.e. short stubby chelicerae and a relatively wide deutosternum, as revealed by Flechtmann and McMurtry (1992) for phytoseiid mites in the genus *Euseius* and also for another pollen specialist, *I. degenerans*. As pointed out by McMurtry and Croft (1997), these morphological features are correlated to pollen feeding. It is still premature to infer that these morphological features represent adaptations because there is no mechanistic basis for linking form and function. Elucidating the adaptive value of these traits will represent an important challenge for future research.

One aspect strikingly missing in all these classifications is food density and food quality.
Sabelis and Janssen (1993) proposed that life histories of Phytoseiidae have evolved in relation to what they termed the food density characteristic for each prey species (in short: characteristic prey density). This refers to the amount of food per unit leaf area occupied by the prey species (or infested by the herbivore species utilized as prey). Clearly, spider mites in the genus *Tetranychus* represent the most profitable food source in terms of food density than for example spider mites in the genus *Panonychus* (which use silk for attachment, not to produce a web) or insects (thrips, whiteflies) that have only a short developmental ‘window’ of vulnerability to predatory mites. It is especially this group of *Tetranychus* mites that protects itself against predation by creating silken webs and it is this group that represents prey of a group of highly specialised predatory mites with high rates of population increase (e.g. *P. persimilis*, *P. macropilis* and *P. longipes*). One would also expect these herbivorous mites to sequester secondary plant metabolites or to produce toxins for protection against predatory mites. This may explain why not all genotypes of *P. persimilis* are suitable to control *Tetranychus urticae* Koch on tomato (Drukker et al., 1997 and unpublished data) and why not all *P. longipes* genotypes are suitable to control *Tetranychus evansi* Baker & Pritchard on tomato and other solanaceous plants (Furtado et al., 2007). Also, there is increasing evidence that poor settlement of phytoseiids from surrounding vegetation is due to strong selection in the post-dispersal crop environment (Tixier et al., 1998, 2000, 2002). This is a very intriguing result with explanations varying from selection acting on adaptations to the leaf hair patterns or to the secondary metabolites in the plant and in their prey. It is also interesting to note that generalist predators may actually be an ensemble of genotypes with specialisations on quite different prey, as shown for the case of *H. aculeifer* by Lesna and Sabelis (1999, 2002). We therefore conclude that given the structure of the target crop and target prey environment potential predatory mites for biological pest control can be identified to some extent from patterns of setae on the dorsal shield, that there might be morphological adaptations (e.g. short, stubby chelicerae) predicting an ability to feed on alternative, plant-provided foods, such as pollen, that preference for broad classes of prey taxa might be predictable (e.g. ability to penetrate webs is a necessary condition to feed on *Tetranychus* sp. and this is reflected in setal patterns), but that preference for (specialisation on) certain prey species is hard to predict from morphological traits and require experimental assessment at the species, population or even genotype level (e.g. ability to penetrate webs is a necessary, but not a sufficient condition to feed on certain species of *Tetranychus*).

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Using bees to disseminate multiple fungal agents for insect pest control and plant disease suppression in greenhouse vegetables

Les Shipp¹, Jean Pierre Kapongo¹, Peter Kevan², John Sutton², Bruce Broadbent³
¹Agriculture and Agri-Food Canada, Harrow, ON Canada N0R 1G0, E-mail: shipppl@agr.gc.ca; ²Department of Environmental Biology, University of Guelph, ON, Canada N1G 2W1; ³Agriculture and Agri-Food Canada, London, ON Canada N5V 4T3

Abstract: The bumble bee (Bombus impatiens) was used to vector a combined inoculum consisting of Beauveria bassiana (BotaniGard 22 WP) and Clonostachys rosea (ADJ 710 OMRI) in greenhouse tomato and sweet pepper for simultaneous control of insect pests (Lygus lineolaris and Trialeurodes vaporariorum) and plant disease suppression of grey mould. Four densities, 1) $6.24 \times 10^{10} + 1.38 \times 10^{8}$; 2) $6.24 \times 10^{10} + 1.38 \times 10^{7}$; 3) $3.12 \times 10^{10} + 1.68 \times 10^{8}$; 4) $9.36 \times 10^{10} + 1.06 \times 10^{8}$ conidia of $B$. bassiana and $C$. rosea respectively per g of inoculum and 5) a control (bees, but no inoculum) were assessed. Ninety-six, 47 and 88% of the bee, pest insect and plant samples contained detectable amounts of $B$. bassiana and $C$. rosea. Infection levels for both pest species, as well as disease suppression were greatest at the highest concentrations of both agents. However, bee mortality was also significantly greater at the highest concentration of $B$. bassiana. Therefore, the optimal combined concentration ratio of $B$. bassiana and $C$. rosea was $6.24 \times 10^{10} B$. bassiana + $1.38 \times 10^{7} C$. rosea.

Key words: bee-vectored fungal control agents, Beauveria bassiana, Clonostachys rosea, Botrytis cinerea, Lygus lineolaris, Trialeurodes vaporariorum

Introduction

Bees are able to disseminate many types of microbial agents (bacteria, fungi and viruses) (Kevan et al., 2007). Honey bees and bumble bees were found in the early 1990s to be able to deliver the fungal agent (Clonostachys rosea) to flowers for plant disease suppression (Peng et al., 1992; Yu & Sutton, 1997) and later to vector insect fungal agents for pest control (Kevan et al., 2007; Kapongo et al., 2008). Thus, bees can be used to vector Beauveria bassiana for insect control and C. rosea for suppression of grey mould disease. Krauss et al. (2004) reported that B. bassiana and C. rosea were compatible with each other in laboratory trials. The ability to use bee pollinators to disseminate microbial agents to the plant for insect pest control and plant disease suppression is a labour saving cost as opposed to spraying the agents on the crop, delivers continuously the agents to the crop whenever the bees are active, combines pollination services with pest and disease control, and delivers the microbial agents to where the pests and disease pathogens are located on the plant (flowers and leaves) as opposed to the air and substrate.

The objective of the present study was to determine the optimal concentration ratio of B. bassiana (BotaniGard 22 WP) and C. rosea (ADJ 710 OMRI) when combined as a single bee-vectored inoculum for control of insect pests and suppression of grey mould disease on greenhouse tomato and sweet pepper.
Material and methods

The trials were conducted during 2007 in two greenhouse compartments (7 × 13 m) with two or three fine-mesh screened cages (520 × 240 × 220 cm high) per greenhouse. Each cage contained 64 potted sweet pepper or tomato plants with a minimum of two flower sets per plant and one colony (50 workers and 1 queen) of bumble bees (Bombus impatiens). The cages were maintained at 21-23°C and 80-85% RH throughout the trials. A completely randomized design was applied for the five treatments with three replications over time. The treatments were: 1) 6.24 ×10¹⁰ + 1.38 ×10⁸; 2) 6.24 ×10¹⁰ + 1.38 ×10⁷; 3) 3.12 ×10¹⁰ + 1.68 ×10⁸; 4) 9.36 ×10¹⁰ + 1.06 ×10⁸ conidia of B. bassiana and C. rosea respectively per g of inoculum; and 5) a control (bees, but no inoculum).

Each colony of bumble bees was introduced one day after the plants were placed in the cages to allow for acclimation to their hive and the cage. On day 2, 256 adult Lygus lineolaris were released per treatment for the pepper trials and 1,000 adult greenhouse whiteflies, Trialeurodes vaporariorum, in the tomato trials. On the same day, the leaves and flowers of 12 randomly selected plants per treatment were artificially inoculated with spores of Botrytis cinerea (grey mould pathogen). Wooden dispensers filled with the appropriate inoculum (empty dispenser in the control) were placed in front of the hives on day 3. The first sample (50 adult Lygus and T. vaporariorum, and 24 flowers and leaves) was collected on day 6 after which the dispensers were removed. The dispensers were refilled and replaced day 10, and a second sample was collected three days later. Five bees were also sampled from each treatment at each sampling date to determine the amount of Beauveria and Clonostachys that the bees were carrying.

Ten Lygus and T. vaporariorum per sample were surface sterilized following Shipp et al. (2003) to estimate internal infection levels. Samples were then placed on water agar plates, incubated at 25°C and 80% RH for five days before checking for sporulation using a dissecting microscope. Another 10 Lygus and T. vaporariorum, 5 bees, and 12 flowers and leaves per treatment sample were washed to determine the amount of conidia that individual pests or plant parts carried/received using the protocol of Kapongo et al. (2008).

The remaining Lygus and T. vaporariorum were used to assess the percentage mortality caused by Beauveria. Each insect was individually kept for seven days in an aerated Petri dish (Lygus) or an aerated sealed plastic vial (whitefly) containing organic lettuce or the growing point of a tomato plant, respectively as a food source. All bioassay cages were inspected daily for insect death. The appearance of white mycelium on cadavers indicated Beauveria infection. The remaining 12 leaves and flowers were placed individually on moistened filter paper in sealed Petri dishes and incubated for 14 days at 25°C and 80% RH. After incubation, ten 10-cm diameter disks were cut at random sites on each leaf and flower by means of cork borers that were surface-disinfected in sodium hypochlorite and washed in sterile water before each excision. Sporulation of grey mould was assessed following the protocol of Sutton et al. (2002) using a dissecting microscope to determine the incidence and percentage area of tissue pieces with conidiophores.

Mortality of the bumble bees exposed to the five treatments was determined after the second sampling. Each bumble bee colony was transferred back into the commercial hive boxes and fed pollen patties mixed with 50% wt/wt sugar solution for five weeks. The percentage of bumble bee mortality was recorded weekly.
Figure 1. Mean (± s.e.) percentage mortality of insects when exposed to the five bumble-bee vectored densities of the combined *B. bassiana/C. rosea* inoculum in greenhouse cage trials of tomato and pepper for insect pest and plant disease control. Treatments assigned the same letter are not significantly different (protected LSD, *P* ≤ 0.05) using *F*-test.

Figure 2. Mean (± s.e.) percentage of grey mould suppression on flower and leaf samples from tomato and pepper when exposed to the five concentration ratios of the bumble-bee vectored *B. bassiana/C. rosea* inoculum. Treatments assigned the same letter are not significantly different (protected LSD, *P* ≤ 0.05) using *F*-test.
Results and discussion

Ninety-six, 47 and 88% of the bee, pest insect and plant samples contained detectable concentrations of *B. bassiana* and *C. rosea* for both crops for all treatments, except the control treatment in which neither fungal agent was ever detected. The amount of *Beauveria* per *T. vaporariorum* sample ranged from 21-90 conidia per adult. In the mortality bioassays for the insect pests, the bumble-bee disseminated inoculum caused a mortality range of 53-74% among the four *Beauveria* treatments for the *Lygus* samples (Figure 1). Fifty-six to 83% of the dead *Lygus* exhibited mycosis. No mycosis was found in the control samples. Internal infection levels ranged from 31-50%. A similar relationship was found for *T. vaporariorum* (Figure 1). Bee mortality was not significantly different among T1 to T3 and T5 (control). For T4 (highest *Beauveria* concentration), bee mortality ranged from 47-59% between the two crops. Grey mould suppression for the flower and leaf samples ranged from 38-79% for both crops (Figure 2). Results obtained from this study were similar to data reported when both fungal agents were evaluated separately.

In summary, the combined concentration ratio of $6.24 \times 10^{10} + 1.38 \times 10^7$ conidia of *B. bassiana* and *C. rosea* per g of inoculum is the optimal concentration ratio for both agents for insect pest control and plant disease suppression based on pest control efficacy, disease suppression and minimal impact on bee mortality. The next step is to determine the impact of these fungal agents on non-target organisms and to conduct commercial efficacy trials.

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Commercial application of beneficial insects in Canadian nurseries

Brian Spencer
Applied Bio-nomics Ltd., 11074 West Saanich Road, North Saanich, British Columbia, Canada, V8L 5P5, E-mail: brianabl@telus.net

Abstract: Commercial applications of beneficial insects and mites have largely been limited to glasshouse production of food crops, such as pepper, tomato and cucumber. In the past decade, many of the same traditional commercial beneficials for biological controls have been used in outdoor nurseries, with excellent results. Today, many commercial nurseries use biological control as the primary pest control method. Many of the traditional beneficials have also found new applications.

Introduction

Many of the commercially available beneficial insects used in glasshouse crop protection have found new uses in outdoor nurseries. Tropical specialists such as Phytoseiulus persimilis perform their usual tasks outdoors as long as they aren’t frozen to death.

In most temperate climates, the tropical beneficials have a surprisingly long, effective working season, usually well beyond the normal “frost free” period, as the plants they are working on offer some protection. Most of the tropical beneficials do not have any natural cold protection mechanism, so while the native invertebrates are being triggered into some form of diapause, the tropical beneficials continue to perform until they actually do freeze to death.

Beneficials native to the temperate climates can offer the outdoor nursery continuous, year after year control, if they are suited to the plants, growing substrate, climate and pests.

Some traditional beneficials used in glasshouses have found new applications and hosts in outdoor nurseries, offering the potential of preventing significant crop loss in many, hard to chemically control, situations.

Discussion

Applied Bio-nomics Ltd. has more than 20 years of experience working with outdoor nurseries, providing beneficials for many different crops and their pests. We are situated on the west coast of British Columbia, where it is still possible to find true, native plants. A few of the commercial nurseries on the west coast of North America specialize in these “Native Plants”. In our years of experience, the true “native plants” do not need any pest control. Pest “outbreaks” are not seen on true natives.

Ornamentals, by their definition, are either exotics or bred to be exotic. In most cases, these plants encounter some form of physical stress either from the climate, the soil substrate, the angle of the sun, the availability of nutrients and micro-nutrients or any other external force. These are the plants that need continuous pest protection.

Most nurseries produce a broad range of plant products. This diversity can be used to an advantage by the grower, especially if the grower keeps a detailed diary. The diary should contain observations such as which varieties of plants are favoured by the pest, when the pest was first noticed, what controls worked, where were the plants located, etc.
Accumulated heat units are not only a good indicator of plant development; they are also very accurate indicators of when to expect a reoccurrence of the pest. In some areas of North America, such as the US state of Oregon, the Government provides access via the internet to regional weather stations. A grower in a specific region can log on to the site and see how many accumulated heat units there are, and other important information. If this service is unavailable, an even more accurate method exists within the accurately kept diary. By noting what shrubs, trees and plants are flowering when a pest is first observed, it is repeatable in subsequent years. This is how trees and shrubs get names such as “salmon berry”.

For some pests, such as some species of scale, which have one life cycle per year, the crawlers will be active and vulnerable at the same heat unit point each year, or when that certain shrub is flowering again.

By knowing when to look for pest problems, the grower can be more focused and prepared.

**Amblyseius fallacis**

A few of the commercially available biological control products were actually developed for outdoor, field use. The predatory mite, *Amblyseius fallacis* was originally found in an apple orchard in Ontario, Canada. It’s resistance to most of the organophosphate pesticides made it a candidate for the British Columbia field strawberry crop, which was in peril due to all of the registered miticides being withdrawn. The growers were convinced that a spray program was essential against aphids, which were carriers of a devastating virus. Trials of *A. fallacis* were very positive in the strawberries, and establishment was persistent. After initial inoculations of 10,000 mites per acre, only about half of the strawberry growers reintroduced the following year, at 5,000 mites per acre. In the third year, virtually no mites were needed.

Commercially, *A. fallacis* was a bust! Luckily, for Applied Bio-nomics Ltd. anyway, *A. fallacis* was found to be effective for controlling spider mites in the US mint fields, mostly situated in Montana. The mint growers suddenly embraced the concept of biological control, when the buying groups of the mint oil started using mass spectrometers to detect adulteration and contaminants. The pesticide spikes were quite obvious. But, despite Montana’s harsh winters and high elevation, *A. fallacis* once again established, and, once again, after the third year, no new sales of *A. fallacis* were made to the mint growers.

We knew we had an excellent mite for biological pest control, but commercially we were not able to develop a market that could be sustained. *A. fallacis* during the next few years was used preventatively on three tomato greenhouses in New England to control Russet mite. Once again, the control was persistent and sales stopped. While Applied Bio-nomics Ltd. was planning an orderly shutdown of *A. fallacis* production, trials in Oregon on the Bamboo mite, showed that *A. fallacis* was the best candidate for biological control. It was also the only mite in the trial that was able to penetrate the silky cocoon of the Bamboo mite. This time it took 5 years to saturate the market, once again providing persistent control. In those 5 years, however, we were able to develop strategies with *A. fallacis* in greenhouse pepper and save its’ commercial life.

Today, in nurseries, *A. fallacis* is used extensively in woody ornamentals, primarily in the evergreen trees, where it controls all of the pest mites that we have encountered to date. *A. fallacis* has also been used in boxwood and other broad leafed evergreen and deciduous shrubs.

**Aphidoletes aphidimyza**

The predatory midge *Aphidoletes aphidimyza* has been used in Victoria’s famous Butchart Gardens, for over 20 years. It has been used throughout the gardens to control all species of
aphid. *A. aphidimyza* has also been used by many municipalities throughout North America to control boulevard and municipal park shade tree aphid infestations. Cities from Santa Barbara, California to Montreal, Quebec have used *A. aphidimyza* successfully.

Some of the largest commercial woody ornamental producers, such as Hines Nursery, and Monrovia Nursery, which have production facilities throughout the US, have relied on *A. aphidimyza* and many other biological controls. The Hines facility in Oregon uses *A. aphidimyza* for their shade tree production, finding, like *A. fallacis*, that applications establish and persist for many years.

*A. aphidimyza* was used on Christmas trees in Oregon to control an aphid that was attracted to the firs. An initial release of 10,000 per acre was only used once; with full and persistent control resulting. *A. aphidimyza* has proven effective against almost every aphid we have encountered. A trial was done on the giant, Willow aphid, in British Columbia. Within 2 weeks, the aphids were completely eliminated.

About 10 years ago, *A. aphidimyza* was used as a control for an evaluation of a beetle, *Pseudoscymnus tsugae*, being developed in New Hampshire to control the Hemlock Wooly Adelgid. I have never seen anything published, but the researcher was quite upset that the *A. aphidimyza* outperformed *P. tsugae*.

**Hypoaspis miles**

Perhaps the most commonly used biological control is *Hypoaspis miles*. This mite has been used for control of fungus gnats in almost every form of propagation and in almost every media. *H. miles* has been sprinkled over dormant tulip bulbs in Holland to control the bulb mite. It has been sprinkled into Tarantula cages to control the tracheal mite associated with crickets. It has been used for years to control the Cactus Root Mealybug, and, in British Columbia, it has been used to control and eliminate the Black Vine Root Weevil.

The first trial for control of the Black Vine Root Weevil was in my backyard, where I had planted about 20 different Rhododendrons. After a couple of years in the ground, all of my plants were severely infested with the Black Vine Root Weevil. In late summer, about 15 years ago, I used a bottle of *H. miles* on the Rhododendrons, placing about 1,000 mites at the base of each plant. The following spring, all of the new growth showed no notching, completely clean new growth. The Black Vine Root Weevil larvae, that in the previous year were very easy to find, could not be found. In the 15 years since that one application, there has never been a notch in any of the original 20 Rhododendrons. About 8 years ago, I cleared another section of the property and planted 6 more Rhododendrons. The following year, severe notching was seen in the new planting area. An application that spring of *H. miles* lead, once again, to no notching, and no trace of the Black Vine Root Weevil larvae.

Based on the original discovery, 10 years ago, we approached a municipal garden in Victoria, B.C. called Government House. The head gardener liked the idea of biological control of the Black Vine Root Weevil and gave us the western half of the 4 acre garden to treat with *H. miles* while he continued to use Diazinon on the eastern half. The treatment was done in the early spring, and at the end of the summer, we were very disappointed to find significant notching and still easily found larvae. The gardener was not as discouraged as we were, however, pointing out that our half of the garden was no worse than his, Diazinon treated side. We let the whole project drop, thinking that my experiment in my yard was just another uncontrolled experiment with too many variables to manage.

The following year, in late spring, the head gardener called us up and asked us to come back for a visit. When we arrived it was obvious what his call was about. The west side of the garden had no notching on all of the new growth, while the east side was still notched, as was normal. The gardener explained that, based on our trial, he stopped using Diazinon altogether.
We gave him enough *H. miles* to do the east side and to date, the Black Vine Root Weevil has not been a pest problem at the garden.

Four years ago Robin Rosetta, from Oregon State Extension, Willamette, had 2 weeks left with a researcher and some Black Vine Root Weevil eggs, so she agreed to rush a simple experiment, presenting Black Vine Root Weevil eggs to our *H. miles* in a Petri dish. Once again, we were disappointed with the results. Out of 10 presentations, only one dish showed any form of feeding on the eggs. A review of the experiment showed that the eggs may not have been viable, which, combined with research that showed *H. miles* was only attracted to moving prey, suggested that we should still continue our quest despite the continuing disappointments.

After discussions with Dave Gillespie, *H. miles*’ original developer, there was some evidence that *H. miles*’ method of prey consumption could include a swarming behaviour, suggesting that we were looking in the wrong area when considering feeding on the eggs, and that the early instars and perhaps the eggs moving prior to hatching, may be where the predation is occurring. Dave has since sent me a picture of *H. miles* swarming a large larvae.

During all of these years, we have been using *H. miles* to control the Strawberry Root Weevil, which is a significant pest in the Pacific Northwest on ornamentals. Once again, the control is persistent. *H. miles* in our strategies is a cornerstone. It is able to withstand any winter, it feeds on overwintering pests that find protection in the soil, and it feeds on soil pupating pests, such as some species of thrips, during the main growing season.

**Conclusion**

The use of beneficial insects and mites in woody ornamental nurseries is widespread throughout North America. From propagation all the way through to planting in the consumers yard, beneficials play a significant role in plant protection, pest control, soil aeration, and ultimately to a “value added” role at the wholesale and retail sale.
A preliminary predictive model for the consumption of powdery mildew by the obligate mycophage *Psyllobora vigintimaculata* (Coleoptera: Coccinellidae)

Andrew Sutherland, M.P. Parrella
Department of Entomology, University of California, Davis, CA, USA, E-mail: asutherl@ucdavis.edu

**Abstract**: Powdery mildews are important plant pathogens worldwide, often warranting chemical control measures. Effects on non-target organisms and resistance concerns have recently prompted the consideration of biological control. A cosmopolitan coccinellid tribe (Psylloborini) is composed of obligate consumers of powdery mildew. A western North American species, *Psyllobora vigintimaculata*, is being evaluated for its ability to consume spores and hyphae of mildews in greenhouses, in an attempt at augmentative biological control. A predictive consumption model has been created utilizing known biological attributes of the insect, a modified Leslie matrix, and an individual larval consumption model. The model has then been employed to simulate the population growth and subsequent removal of visible mildew colonies by the insects in a closed and controlled horticultural system. When compared against real data from a greenhouse efficacy trial, the model slightly underestimates consumption. Model limitations and assumptions are discussed. The possibility of using such a model as a calculator to determine optimum insect release rate in a system with known parameters is also discussed.

**Key words**: powdery mildew, biological control, release rate, matrix modelling

**Introduction**

Fungi commonly known as powdery mildews (PM), belonging to the order Erysiphales (Ascomycota), have been known to infect over 10,000 species of angiosperm plants (Amano, 1986). Many of these plants include important agricultural and horticultural crops. Thus, PM as a group are collectively considered as one of the most important plant pathogens worldwide. Conventional management of PM involves the liberal use of chemical fungicides. Chemical management can be problematic due to the geometric reproductive ability of these fungi and their subsequent development of resistance to the fungicides being used against them (McGrath, 2001). Additionally, there are concerns about the effects fungicides may have on nontarget beneficial arthropods present in the crop. Sulfur, a commonly-used elemental PM fungicide, is quite toxic to predatory mites (Phytoseiidae), and the use of strobilurin fungicides has been associated with a decline in populations of aphidophagous coccinellids in apple orchards (Michaud, 2001). Biological control of PM may offer a solution to these problems and may prove to be a sustainable element of a responsible integrated disease management program. The coccinellid tribe Psylloborini (Halyziini) is comprised entirely of obligate consumers of PM at all mobile life stages (Gordon, 1985). Species within this tribe have been shown to remove and reduce PM hyphae and conidia on infected plants to a significant degree (Soylu *et al*., 2002; Sutherland & Parrella, 2006). A Nearctic species, *Psyllobora vigintimaculata*, is being evaluated as an augmentative biological control agent (BCA) in horticultural systems and as a PM indicator in agronomic systems (Sutherland, 2005).
The average quantity of target pest consumed/dispatched by a BCA during its lifetime can be fundamental to its success. A linear model that predicts the amount of leaf area that is cleaned of all visible PM colonies during the larval experience (egg to adult) of one *P. vigintimaculata* individual has recently been constructed through laboratory observation, digital photography and the use of image analysis software (Sutherland & Parrella, 2006). This model deals with only one larva at a time, and so has problems predicting the quantity of PM that will be consumed by a fluctuating population of *P. vigintimaculata* composed of many individuals of varying ages. The population growth and population structure at some point in time of any organism with known life stages, durations of life stages, developmental rates, mortality coefficients and fecundity can be determined through the use of matrix mathematics, specifically of the type defined by Leslie (1945). By combining the linear individual consumption model with a Leslie matrix population vector model we hoped to construct a population level consumption model that can be used to quantifiably predict the ecological service of PM removal offered by this insect species in any horticultural system with known parameters.

**Materials and methods**

The constructed model consisted of several components; temperature dependant growth, fecundity, survival probabilities, consumption constants for each life stage (as determined by the linear larval consumption model), population composition over time (as determined through use of the Leslie vector matrix model); and several driving variables including the total crop leaf area, the initial PM severity (expressed as % leaf area visibly infected) and the number of adult female *P. vigintimaculata* released into the system.

In order to simulate individual development over time we used the concept of thermal unit accumulation. The thermal units (degree days) required for each developmental stage were previously determined (Sutherland, 2005) through laboratory observation at static temperatures using a lower developmental threshold, $T_0$, of 10°C within the rectangular accumulation formula $DD=\sum(T_{\text{mean}}-T_0)\text{day}$ (Arnold, 1959), predicting an egg to adult life cycle of 234.9 degree-days. Fecundity data (~7 eggs/female/day) were from previous observation. Mortality was estimated to be 5%.

In order to estimate the total amount of leaf area cleaned (LAC) of PM by individual during larval development we utilized a linear consumption model that included a measure of normal PM growth (G) that should occur. Data resulting from young (egg to 2nd instar) and old larvae (3rd instar to pupa) were viewed as continuous, representing PM consumption for the entire larval duration. The constructed model was as follows:

$$LAC_{\text{total}} = LAC_{\text{young}} + LAC_{\text{old}} + G_{\text{young}} + G_{\text{old}}$$

where $LAC = (\%PM_{\text{initial}} - \%PM_{\text{final}}) \times 23.7 \text{ cm}^2$ for larva units, and $G = \text{mean } (\%PM_{\text{final}} - \%PM_{\text{initial}}) \times 23.7 \text{ cm}^2 \pm \text{standard error for all untreated units}$.

The Leslie growth matrix model describes development, age specific mortality, and reproduction. The major variables/parameters are $N_{x,t}$, the number of organisms in age $x$ at time $t$; $S_x$, the survival probability during age interval $x$ to $x+1$; and $M_x$, the average number of offspring produced in age interval $x$ to $x+1$. There are two base equations:

$$N_{x+1,t+1} = N_{x,t} \times S_x \quad \text{(development and mortality)}$$

$$N_{0,t+1} = \sum N_{0,t} \times M_0 + \ldots N_{x,t} \times M_x \quad \text{(# individuals in the first age class)}$$
These two equations can be combined into one matrix equation: \( N_{t+1} = A \times N_t \), where \( N_t \) is a vector of age distribution at time \( t \) and \( A \) is the transition matrix. This equation can be iterated to simulate as many time steps as necessary. From this conceptual design a spreadsheet was adopted and modified that required only the input of an initial population, a probability coefficient for each stage to remain in that stage (diagonal), a probability coefficient for each stage to move up a stage (sub diagonal), and a measure of fecundity of adult females. This program could then simulate generations (or thermal unit steps) and generate an age distribution vector, \([P]\). The final model structure, which deals with a dynamic population and different age-specific feeding rates, is as follows:

\[
\%PM \times LA = [LAC] \times [P] \times A
\]

where \( \%PM \) refers to the initial PM severity, \( LA \) refers to the crop leaf area, \([LAC]\) is a vector of larval feeding rates at all four instars, \([P]\) is the population vector from the Leslie matrix, and \( A \) is the number of adult females released. Control of PM in a given system is reached when the equation is satisfied. A release rate calculator equation was generated by solving for \( A \) such that \( A = (\%PM \times LA) / ([LAC] \times [P]) \).

There are several key assumptions made with this model:

1. PM growth is built into the individual consumption model and is based on laboratory observations in an incubator. Greenhouse conditions may differ.
2. The leaf area within a system does not change over time.
3. PM spore density is uniform.
4. Adult beetle sex ratio is exactly 50/50.
5. Mortality, development, PM consumption and fecundity are uniform over each age class for all individuals.
6. Adult beetles do not consume PM.

This last assumption is especially problematic since we know the adults of both sexes do indeed consume PM, but since we have no data on how much is consumed it is not included in the model. Consumption data from the linear feeding model were based entirely on larvae. In nature, or in a large variable system such as a greenhouse, we expect the adults to be concerned with dispersal and reproduction in addition to feeding.

In order to compare the behaviour of this model to real data, we have carried out a short and simple experiment, doubling as a feeding efficacy trial, to generate the needed data. Uniformly infected Transvaal daisies, \( Gerbera jamesonii \), were placed in community cages (five 8” potted plants per 2 m\(^2\) cage) within a greenhouse at the UC Davis campus. One of three treatments; 0 (control), 25 or 50 beetles released, was then instituted. Weekly leaf samples were taken from each plant for a total of five weeks in order to assess the PM% of the three treatments over time. A destructive harvest was initiated at the end of the trial and leaves from each plant were run through a leaf area meter (LI-3100, LiCor Inc.) to determine the final (and assumed initial) leaf area of each plant.

**Results and discussion**

Simulated data slightly underestimated the actual PM removal as recorded through digital photography for both release rates (Table 1). The simulated final \( \%PM \) for the 50-beetle treatment was very close to the real data at the end of the trial. The real data showed fluctuation with a PM severity peak one week after beetle release and a small peak three
weeks after release. The release rate calculator determined that 77 beetles (38.5 females) should be released in order to gain control (0%PM) in 30 days. In the greenhouse efficacy trial the 50-beetle (25 female) treatment had reduced %PM to 21.1% at 30 days.

Table 1. Simulated and observed powdery mildew severity (%PM) on caged Gerbera plants exposed to 0 (control), 25 or 50 Psyllobora vigintimaculata adults for five weeks.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Initial</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>12.4</td>
<td>37.5</td>
<td>37.9</td>
<td>39</td>
<td>37.3</td>
<td>55.2</td>
</tr>
<tr>
<td>25 beetles</td>
<td>40.7</td>
<td>50.5</td>
<td>26.1</td>
<td>30.2</td>
<td>28.1</td>
<td>13.7</td>
</tr>
<tr>
<td>50 beetles</td>
<td>30</td>
<td>27.8</td>
<td>24.4</td>
<td>26.7</td>
<td>21.1</td>
<td>8.38</td>
</tr>
<tr>
<td>MODEL25</td>
<td>40.7</td>
<td>39.7</td>
<td>36.8</td>
<td>34.7</td>
<td>32.7</td>
<td>30</td>
</tr>
<tr>
<td>MODEL50</td>
<td>30</td>
<td>27.9</td>
<td>22.2</td>
<td>17.9</td>
<td>13.9</td>
<td>8.54</td>
</tr>
</tbody>
</table>

Since adults were not included in the [LAC] feeding model, the model will always underestimate the actual cleaning being done. Also, there may be physiological differences in the PM species compared here: Zinnia PM tends to be dense and patchy, whereas Gerbera PM tends to be diffuse and uniform. It is possible that there was less PM growth in this trial than in the laboratory trial, which supplied the PM growth portion of the model. Clearly more real data from more varied systems are required in order to observe the model’s behaviour, calibrate the model for use in the real horticultural world, and to validate the ability of the model to predict consumption and organism growth.

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Experimental studies on *Typhlodromips (Amblyseius) swirskii* in greenhouse cucumbers

Y. Trottin-Caudal¹, J.-M. Leyre¹, V. Baffert¹, C. Fournier¹, C. Chabrière²
¹Centre Technique Interprofessionnel des Fruits and des Légumes, BP 32, 30 127 Bellegarde, France, E-mail: trottiny@ctifl.fr; ²Association Provençale de Recherche et Expérimentation, Route de Mollégès, 13210 St Rémy de Provence, France

Abstract: The major pests on cucumber are whiteflies and thrips. Trials were conducted to evaluate the efficacy of *Typhlodromips swirskii* released in sachets in greenhouse cucumber crops in the Southeast of France as well as studying the side effects of a few chemical products in field tests. *T. swirskii* was an excellent predator of thrips and whiteflies at the dose of one sachet per three plants. Among tested products, only Vertimec (abamectin) showed a real toxicity on the predator.

Key words: *Typhlodromips (Amblyseius) swirskii*, cucumber, greenhouse, toxicity, chemical product

Introduction

The two major pests on protected cucumber crops are whiteflies (*Trialeurodes vaporariorum* Westwood and *Bemisia tabaci* Gennadius) and thrips (*Frankliniella occidentalis* Pergande). These pests can cause serious damage on plants, especially on fruit, making them non-marketable. In France, beneficials are currently released on more than 80% of protected cucumber crops (Bertrand *et al.*, 2007). The most frequent are *Amblyseius cucumeris* on thrips and the parasitoids *Encarsia formosa*, *Eretmocerus eremicus* and *E. mundus* on whiteflies. Recent studies reported the efficacy of *Typhlodromips swirskii* Athias-Henriot for control of the two whitefly species and thrips, especially on cucumber (Pijnakker & Messelink, 2005; Ridray & Lacordaire, 2006; Calvo & Belda, 2007). Trials were set up on cucumbers in 2006 and 2007 in experimental greenhouses at the Ctifl centre, and in commercial plastic tunnels in the Southeast of France. The efficacy of different strategies of *T. swirskii*, released in sachet or in bulk, was evaluated as well as the side-effects of a few products in field tests.

Materials and methods

Studies were carried out in experimental 60 m² insect-proof glasshouses. Cucumbers (cv. Aramon, Avalon (Rijk Zwaan)), were grown on rockwool substrate, 12 plants/row (1.2/m²).


Two trials were carried out and each treatment was confined to a separate glasshouse. The plants in the 4 central rows in each glasshouse were artificially infested with whitefly and thrips (adults, nymphs) a few days after planting. *T. swirskii* sachets (Koppert) were introduced at 2 rates, at the 2nd and 3rd instar of whitefly nymphs (1st trial) or at the 4th stage-puparium of *T. vaporariorum* and egg and 1st stage of *B. tabaci* (2nd trial). The incidence of regular releases of prey to simulate external entries on the efficacy of *T. swirskii* was also evaluated as well as the efficacy of *T. swirskii* released in bulk in the nursery (Table 1).
Observations were carried out weekly on 8 plants/row and 4 replicates, at three levels (top 50 cm; at 1.5 m; low level) of the main stem of the plant, and on 1 large leaf per level. Whitefly adults and L4-puparium, thrips adults and larvae and the late instar pinkish stages of *T. swirskii* were counted on each leaf. The whitefly adults were counted on a random sample of 12 plants among the 48 plants in the 4 central rows.

**Side effects of a few chemical products on *T. swirskii* (2007)**

Two trials were conducted. Products were chosen among the registered and most used on cucumber. Whiteflies were introduced on the plants just after planting (1st trial) or earlier in the nursery to have a quicker establishment of the predator mite (2nd trial). Additional infestations of whiteflies *B. tabaci* (*Bt*), *T. vaporariorum* (*Tv*) and thrips (*Fo*) were made when needed. *T. swirskii* was released at the dose of 1 sachet/3 plants (Table 2). Application of the products was done 3 weeks after the releases on well-established predator populations.

An experimental sprayer equipped with a lance, on the base of 1000 l/ha, at 5 bars of pressure was used. Two applications at 7-day intervals were done in the 2nd trial because of the low toxicity of the products observed 8 days after the first one. Observations were carried out on J-1 (J, treatment day), J+4, J+6 and J+8, J+14 and J+20 for the 1st trial and J-1, J+2, J+8, J+10, J+15 and J+20 (J, first application day). Observations were done as in the previous trials: whiteflies, thrips and *T. swirskii* (only the pinkish forms in the 1st trial and all the mobile stages in the 2nd trial) were monitored.

**Table 1. Strategies tested and releases of prey *B. tabaci* (*Bt*), *T. vaporariorum* (*Tv*), *F. occidentalis* (*Fo*) and of *T. swirskii* (*Ts*).**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Treatments</th>
<th>Total releases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st, 28. March</td>
<td>Control (water)</td>
<td><em>Ts</em> 1 sach/pl</td>
</tr>
<tr>
<td>2nd, 24. July</td>
<td>Control (water)</td>
<td><em>Ts</em> 1 sach/3 pl + releases of prey¹</td>
</tr>
</tbody>
</table>

**Table 2. Tested products, total releases of prey (*B. tabaci* (*Bt*), *T. vaporariorum* (*Tv*), *F. occidentalis* (*Fo*)) and of *T. swirskii* (*T.s*).**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Treatments</th>
<th>Total releases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st, 22. March</td>
<td>Vertimec (abamectin) 0.5 l/ha</td>
<td>Thiovit jet microbilles (sulphur) 7.5 kg/ha</td>
</tr>
<tr>
<td>2nd, 29. Aug</td>
<td>Torque S (fenbutatin oxide) 0.9 l/ha</td>
<td>Mycloss Fort (myclobutanil) 0.375 l/ha</td>
</tr>
</tbody>
</table>
Figure 1. Mean number of *T. swirskii*, whiteflies and thrips (1st trial on the left and 2nd trial on the right). Values followed by the same letter are not significantly different (p> 0.05).

Figure 2. Mean number of predatory mites (top: 1st trial; bottom: 2nd trial). Values followed by the same letter are not significantly different (p> 0.05).
Results and discussion


The mean daily temperature was 22.4°C and 23.0°C and rh was 61.1% and 73.1% respectively in the 1st and 2nd trial. For the first trial, at the middle level i.e. near the sachet, 9 days after the introduction of the sachets, the late stages of T. swirskii were present on all the leaves observed versus a mean proportion of 0.43 of infested leaves respectively in the treatment 1 sachet/plant and 1 sachet/3 plants. At this latter dose, all the leaves were infested 22 days after the sachets were introduced. Then T. swirskii established on all the plants and, especially at the high level where prey were more abundant. There was no establishment of whiteflies and thrips at the two doses of T. swirskii. The average number of predatory mites/leaf was not significantly different. So, in our conditions, 1 sachet/plant seemed to be too high. Moreover, the predatory mite infested the control treatment in the neighbouring greenhouse; consequently, thrips populations were well controlled. However, the efficacy of T. swirskii was not good on a well-established whitefly population. These results are confirmed by the data of the mean number of whitefly adults/plant in the control (on 20/6, 205.3 and only 2.6 and 5.8 per plant, resp. in the treatments 1 sachet per plant or per 3 plants). For the 2nd trial (summer conditions), a quicker establishment of T. swirskii was observed. In the 3 treatments, there was no establishment of the pests. T. swirskii confirmed its efficacy at the dose of 1 sachet per 3 plants. If prey were regularly added, the predator, if well established, was able to control the populations by preventing thrips and whitefly establishment. The predator released in the nursery also gave an effective control under our conditions, in spite of a lower population at the beginning of the trial.

Side effects of a few chemical products on T. swirskii (2007)

T. swirskii confirms its efficacy on whiteflies and thrips in the control treatment with water application. In the 1st trial, the average number of predatory mites increased slightly after the application of water in the control treatment. In the Vertimec treatment, the population decreased more or less after the application and was significantly lower than the control from 18th May. Pirimor G and Thiovit jet microbilles, seemed to have a slight incidence on T. swirskii even if the mean number of T. swirskii/leaf was significantly lower than in the control on 30th May. In the 2nd trial, the evolution of T. swirskii populations was rather similar to that of the control after the 1st application. After the 2nd application, populations regularly increased in the four treatments. However, in our conditions, it seemed that Mycloss Fort and Nissorun applied twice at 8-day intervals were slightly toxic on T. swirskii (significant difference relative to the control) whereas no toxicity was observed on Torque S (no significant difference).

Conclusion

T. swirskii showed a very good efficacy in experimental cucumber glasshouses. Another study in commercial plastic tunnels in the Southeast of France with an introduction of 1 sachet/3 plants gave similar results: a good establishment of the predator, an effective control of thrips and whiteflies resulting in no chemical treatment on these pests, and healthier plants than in the grower’s supervised chemical reference. Among tested products, only Vertimec, applied once, seemed to show a real toxicity on the predator in our conditions of field tests.
References


Plant health in innovative growing systems

Carin van der Lans, Ellen Beerling, Pierre Ramakers
Wageningen UR Glasshouse Horticulture, Violierenweg 1, 2665 MV Bleiswijk, Post Box 20, 2665 ZG Bleiswijk, The Netherlands, E-mail: pierre.ramakers@wur.nl

Abstract: ‘Closed greenhouses’ and ‘mobile cropping systems’ are important innovations in Dutch glasshouse horticulture. A survey was done on their consequences for (integrated) plant protection. Based on a literature study and interviews with experts, opportunities and threats were identified, as well as aspects requiring further study, with the principle of sustainable horticulture as a guideline.

Key words: pests, diseases, plant health, integrated pest control, innovations, closed greenhouse, mobile growing systems

Introduction

Changes in the cultivation system can have a profound influence on the occurrence and development of diseases and pests, and consequently on biological and chemical crop protection. With the growing awareness of the necessity of sustainable horticulture, there is a need for early incorporation of crop protection (especially integrated pest management, IPM) in the development of new cultivation systems. At the moment two important innovations in glasshouse cultivations are taking place, both with direct and indirect effects on crop protection: 1) mobile cropping systems and 2) closed greenhouses.

The aim of the study was to get insight into the effects of these innovations on plant health (contamination risk, severity of infestation) and pest control (use of pesticides, effectiveness, emission, working conditions) so that threats can be controlled and opportunities seized as long as these systems are still ‘under construction’.

Methodology

Recent reports and web publications about the subject were studied, and people involved in a number of (semi-)commercial systems already in operation were interviewed. These interviewees included growers, project leaders, crop experts, pest control specialists and researchers.

Closed Greenhouses

The Closed Greenhouse concept is meant to save energy, with the opportunity of yield increase by maintaining higher CO₂ levels in the day-time. It was first developed for tomato, and is now implemented in sweet pepper, cucumber, strawberry, pot plants, rose, and phalaenopsis. In the Closed Greenhouse concept ventilation windows are absent or remain (mostly) closed. The surplus of heat is withdrawn by air treatment systems and stored in a deep water-bearing soil layer (aquifer). The air is cooled with water from one side of the aquifer; after passing a heat exchanger, the water is transported to the other side. During the nights or in the winter period, the system is reversed. Air cooling offers the additional
advantage of dehumidification and thus better control of air humidity. Studies in tomato showed that energy savings of 30% and yield increases of 22% are within reach.

Variations on the concept include the less extreme ‘semi-closed greenhouse’ and the Closed Greenhouse concept constructed with a ‘Zigzag’ roof. In semi-closed greenhouses the windows are opened during part of the day. Zigzag is a double-layer fire-resistant polycarbonate, combining excellent insulation capacity with high light permeability. The roof is both ultra-violet (UV) and extreme-infrared (IR) proof.

**Opportunities**

Ventilation windows are an important entrance for flying insects and airborne diseases. In (semi-)closed greenhouses, windows are absent or (mostly) closed.

- As a result there will be no or fewer air-born diseases and pests.
- Exclusion of summer pests will result in fewer pest species to deal with; hence IPM will be easier to manage year-round.

In such greenhouses the climate is controlled to a greater extent. Relative humidity and temperature are more constant and kept at an optimum for plant growth. Due to the forced ventilation climate conditions within the glasshouse are more uniform.

- As a result, the infestation and development of diseases and pests could be better predicted and controlled.

Within limits set by demands of optimal production, conditions favourable for diseases and pests can be avoided. More precisely:

- Avoiding the combination of high temperatures and low humidity may reduce spider mite problems...
- ...as well as stimulate population of pest predators such as phytoseiid mites.
- Better control of overall air humidity may create more opportunities for utilising mycopesticides (e.g., *Verticillium lecanii*, *Paecilomyces fumosoroseus*, *Beauveria bassiana*).
- The possibility of dehumidifying the air may become a tool to reduce fungal infections and attack by tarsonemid mites.
- Distribution of air-borne pesticides is better, due to the forced ventilation.
- With forced ventilation, treatment of the recirculating air for reducing contamination with fungal spores and air-borne insects becomes within reach.
- (Water condensation on) the heat exchanger may act as a spore trap for fungal diseases.

There are several studies on the effects of different light wavelengths on pests (for an overview see Hemming *et al.*, 2006).

- Exclusion of UV radiation (Zigzag roof) is claimed to result in a considerable suppression of a wide variety of arthropod pests (thrips, whiteflies, aphids, spider mites, leafminers).
- As a result of the lower numbers of vectors also fewer viruses are likely to occur.
• Many fungal species need UV for sporulation. The absence of UV may restrain the
development of fungal diseases.
• Little is known about the effect of IR on pests and diseases.

Threats
• Forced ventilation increases the probability of distribution of airborne diseases (e.g.
powdery mildew and Botrytis) and some insects (various thrips species).
• Some pests may benefit from the reduced air humidity (e.g. powdery mildew, spider
mites).
• In a closed greenhouse, accumulation of gases (CO₂, CO, NOₓ, ethylene, sulphur
vapour, SO₂) may have detrimental effects on natural enemies.

With respect to the Zigzag roof the following threats are identified:

• If UV filtering suppresses all kind of insects and mites (see ‘Opportunities’), it may
just as well have a negative effect on natural enemies.
• Recent research showed that bumblebees and honeybees loose their sense of direction
in a glasshouse without UV light. Zigzag roof is therefore not advised for crops that
need pollinators.

Knowledge gaps
Closed greenhouses and related innovations clearly affect the pest and disease complex in the
crops involved. It is not certain what the net effect will be on plant health and crop protection,
but the first practical experiences show a positive consequence for pest control and a
reduction in pesticide use. Research should not only be focused on countering threats, but also
on seizing opportunities to develop sustainable growing systems.

Some significant gaps in our knowledge should be addressed for being better able to
anticipate sustainable plant protection in the years to come. In our study we identified the
following:

• In closed greenhouses we will have more opportunities to manipulate the climate,
within the bandwidth determined by production demands. We should know in more
detail which air humidity levels will prevent fungal diseases.
• The same applies with respect to the performance of some biological control agents.
• What is the effect of internal air circulation on the development of fungal diseases,
pests and their natural enemies?
• Acceptable concentrations of gaseous air components with respect to human well-
being and plant health are known. Some natural enemies (hymenopterous parasitoids,
cecidomyiids) may be more susceptible. This information is needed for an optimal
selection of natural enemies for closed greenhouses.
• It may be necessary to reconsider re-entry times to be respected after applying
pesticides.
• Documented information available about the effects of UV (e.g. stimulation
sporulation of fungi and flight behaviour of insects) is far from sufficient to explain
the claims about general pest and disease suppressing effects of UV filtering.
• What are the effects of UV exclusion on the flight behaviour and efficacy of natural
enemies?
Mobile Cropping Systems

Mobile cropping systems are designed to reduce labour costs and to fully utilise the cultivation space. These systems allow transport of plants on a tablet, in a row or even individually. Each plant is transported periodically to a central working area for harvesting, crop care and – if necessary – for pest control treatment. Crops with regular harvest of flowers or fruits rotate at a relatively high speed. In rose, for example, plants pass the working area daily, and in gerbera, this is approximately three times a week.

Crops which are completely harvested, like pot plants and cut-chrysanthemums, rotate at a much lower speed and only at specified moments. They are transported occasionally to a different compartment for a next growing phase, or finally to be harvested. The compartments differ in temperature, relative humidity and day length. Pot plants may be moved once a week to a central working area for sorting and reshuffling.

At the moment, mobile systems are operational in pot plants, gerbera, rose and some bulb and rhizome forming plants (freesia, alstroemeria). A mobile system for cut-chrysanthemum is being developed with the additional incentive of abandoning soil-depending cultivation. For high wire vegetable crops (fruiting vegetables) mobile cropping systems are less developed.

Threats

The idea of mobile cropping systems is to use all available space for plant production. This makes the crop less or not accessible, with considerable consequences for scouting and pest control:

• Traditional scouting becomes impossible.
• Therefore, in crops with regular harvest, scouting has to be combined with the harvest and cropping in the central working area. Regular personnel are not qualified for taking this responsibility.
• Some growers report that, as a result of the inaccessibility of the crop, they had to increase the use of chemicals.
• Plants have no longer a fixed place in the greenhouse. Mapping hot spots with the aid of sticky traps, colour tags etc., makes no sense anymore. Local treatments with pesticides cannot be delayed until a more suitable moment, as the affected plants will be difficult to trace.

Extra trainings should be offered to the personnel to improve their scouting skills. In cropping systems with a low speed of rotation (e.g., pot plants, cut-chrysanthemums) other solutions have to be sought, like scouting from an air-bicycle or platform hanging and moving over the crop.

• Some mobile systems are designed in such a way, that plant debris and even weeds easily accumulate in unattainable places (underneath rows and tablets), thus reducing sanitation standards for a wide variety of diseases and pests.

Moving the plants itself may have direct and indirect effects on pests:

• Due to disturbance of the plants, flying insects (whiteflies) and sporulating fungi are more likely to become redistributed. The working area itself might become a distribution centre for such pests.
Rather immobile pests (spider mites, mealy bugs) may become redistributed by leaf contact between system units passing each other.

The microclimate of the leaves is influenced by increased air circulation and dehumidification around (small groups of) plants. This might stimulate spider mite development and negatively influence the development of natural enemies, like predatory mites.

Opportunities
The fact that the production area is no longer accessible for visitors and workers was pointed out by the interviewees as a major advantage of mobile growing systems with respect to spreading pests and diseases:

- Lower contamination risk

Mobile systems also creates more opportunities for computerisation and automating:

- A first step is automating scouting with vision techniques, either directly on plants or on insect traps.
- When automated, scouting can easily be intensified with hardly any additional costs.
- Linked to automated (intensified) scouting natural enemies may be introduced more frequently or even continuously.
- Investing in special equipment for introducing natural enemies is more likely to become cost-effective when applied at one fixed place (the central area).
- A future step will be registration of observations via chips, with interesting possibilities for tracking and tracing throughout the chain.
- This will also give the opportunity to remove contaminated plants from the system for disposal or placement in quarantine.

The existence of a central working space appears the obvious for concentrating pesticide treatments, with the following advantages:

- Pesticides can be more precisely applied on infested plants or tablets only.
- Investing in better spraying equipment is more likely to become cost-effective when applied at a fixed place in the routing.
- Ideally the spraying equipment is integrated in a spraying cabin. In this way emission of pesticides to the environment can be virtually eliminated. Excess spraying fluid can be collected for re-use or for controlled discharge.

Finally, in mobile cropping systems using compartments with different climates, crop protection can be optimised within each compartment when taking into account the opportunities and threats the different climates offer. This is especially the case for cut-chrysanthemum, where the mobilisation of the crop introduced the possibility to create different compartments, one for the rooting and long daylight period, a second for the growing phase, and a third for harvest. The different climates in these compartments could result in a different choice of natural enemies. The high humidity in the rooting phase, for instance, is ideal for the application of mycopesticides.
Knowledge gaps
Practical experiences with mobile growing systems are less positive for IPM. We observed a tendency to fall back to traditional chemical crop protection. This is partly because the growers focus on the innovation techniques as they require large sums of financial resources, giving limited attention to complex IPM strategies. Also, some of the new systems exhibited definite imperfections with respect to disease prevention. Discussions with the interviewees revealed knowledge gaps that should be addressed urgently in order to nullify these imperfections:

- The effects of increased air circulation and dehumidification near the leaf surface on the development of diseases, pests and antagonists, are insufficiently known. Botrytis in gerbera was put forward as an important example since this disease continues to develop in the trade channels.
- In an early mobile system for soilless growing of chrysanthemum, control of Pythium became unmanageable. In further developing this disease deserves special attention.
- Growers insist on (further) developing spraying cabins for the working area, as well as spraying robots for the nearly inaccessible production compartment.
- There is a strong need for introducing automatic scouting systems, a technology that is still in its infancy.

Conclusions
Both mobile cropping systems and closed greenhouses offer ample opportunities to develop IPM strategies. We conclude that investments in the development of new techniques is crucial. Next to this, IPM should be prepared to adjust to the demands set by the new system.

Drastic changes in the cultivation systems as described above will undoubtedly affect the pest and disease complex in the crops involved. For some cases, educated guesses can be made, but it is (and probably always will be) impossible to forecast precisely whether a particular new growing system will result in more, less or other types of pests and diseases. It is therefore recommended to monitor and evaluate pest and disease occurrence intensively in new systems as early as possible, when the systems are still in an experimental stage. Considering the major investments involved, it is important that unsustainable growing systems can be adapted or even abandoned before becoming widespread.

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Silene dioica (Caryophyllaceae: Silenoidae) as a reservoir and a hibernation site for predatory mites (Acari: Phytoseiidae)

Anton van der Linden
Wageningen UR, Applied Plant Research, Flower bulbs, Nursery Stock & Fruits, Lisse, The Netherlands, current address: Wageningen UR Greenhouse Horticulture, P.O. Box 20, 2665 ZG Bleiswijk, The Netherlands, E-mail: anton.vanderlinden@wur.nl

Abstract: On leaves of Red Campion Silene dioica (L) (Melandrium rubrum) collected in three successive seasons in The Netherlands, nine species of predatory mite species were identified. Amblyseius andersoni was the predominant species with 74% of the overall number of the specimens. Other species were, in order of abundance: Neoseiulus cucumeris, Euseius finlandicus, Amblyseius graminis, Amblyseius rademacheri, Proprioseiopsis okanagensis, Amblyseius isuki, Typhlodromus pyri and Amblyseius reductus. Amblyseius andersoni was found hibernating on the lower leaves of this plant.

Key words: conservation biological control, banker plants, hibernation

Introduction

In Israel, Ricinus communis is planted inside or around greenhouses as a reservoir for phytoseiid predators, in particular Amblyseius degenerans (Rubin, 1997). In citrus cultures in China Ageratum conyzoides is being exploited to suppress weeds and to support Amblyseius newsami against Panonchus citri (e.g. Kong et al., 2005). On nurseries with hardy nursery stock in the Netherlands, the suitability of Ageratum houstonianum has been tested and several predatory mite species (Euseius finlandicus, Amblyseius andersoni and Neoseiulus cucumeris) were identified (van der Linden & Nouwens, 2005). It is, however, an annual plant and not suitable for predatory to survive the winter. In a search for plants that might act both as a reservoir and as a hibernation site for predatory mites, the perennial Red Campion Silene dioica (L) (Melandrium rubrum) (Caryophyllaceae: Silenoidae) was encountered as a suitable candidate. This paper gives results of sampling predatory mites on Silene dioica since 2005.

Material and methods

Leaves from Silene dioica were collected between 25 July 2005 and 9 October 2007, mostly in a private garden in Kinderdijk, The Netherlands. Some additional samples were taken from the border of a bulb-growing field of the WageningenUR research site in Lisse, and from the border of the orchards of the WageningenUR research site in Randwijk. In all, 213 leaves were examined for mites and insects. The predatory mites were identified with the help of a key for predatory mites commonly occurring in Dutch orchards (Miedema, 1987).

Results and discussion

On average somewhat more than 1 predatory mite/leaf, with a peak of 7 predators on one leaf were found. Red Campion Silene dioica is a perennial plant with red or pink flowers and hairy
stems and leaves. It is a wild plant that grows in various places, but it is also being sold in garden centres.

74% of the predators were identified as *Amblyseius andersoni*. The remaining 26% consisted of *Neoseiulus cucumeris*, *Euseius finlandicus*, *Amblyseius graminis*, *Amblyseius rademacheri*, *Proprioseiopsis okanagensis*, *Amblyseius isuki*, *Typhlodromus pyri*, *Amblyseius reductus* and 11 unidentified specimens (Tables 1 and 2). *Silene dioica* is thus an attractive plant for predatory mites, but the predominance of *Amblyseius andersoni* was only observed at Kinderdijk: On both other locations the species was not even found. This might be the result of surrounding vegetation, as climatological differences between the sites are minimal.

Table 1. Predatory mites found on *Silene dioica* in The Netherlands in 2005-2007.

<table>
<thead>
<tr>
<th>Date</th>
<th>Locality</th>
<th>Nr. of leaves</th>
<th>Presence of food</th>
<th>Number and species of Phytoseiidae</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.VII.2005</td>
<td>Kinderdijk</td>
<td>13</td>
<td><em>Tetranychus urticae</em> <em>Tydeus sp.</em></td>
<td>44 <em>Amblyseius andersoni</em> 1 <em>Neoseiulus cucumeris</em> 1 <em>Amblyseius rademacheri</em></td>
</tr>
<tr>
<td>26.XII.2005</td>
<td>Kinderdijk</td>
<td>1</td>
<td></td>
<td>1 <em>Amblyseius andersoni</em></td>
</tr>
<tr>
<td>27.II.2006</td>
<td>Kinderdijk</td>
<td>9</td>
<td><em>Tydeus sp.</em></td>
<td>5 <em>Amblyseius andersoni</em></td>
</tr>
<tr>
<td>27.III.2006</td>
<td>Kinderdijk</td>
<td>5</td>
<td><em>Czenspinskia lordi</em></td>
<td>3 <em>Amblyseius andersoni</em></td>
</tr>
<tr>
<td>30.IV.2006</td>
<td>Kinderdijk</td>
<td>5</td>
<td><em>Tydeus sp.</em> <em>Thrips larva</em></td>
<td>5 <em>Amblyseius andersoni</em> 13 eggs</td>
</tr>
<tr>
<td>10.V.2006</td>
<td>Randwijk</td>
<td>17</td>
<td></td>
<td>2 <em>Neoseiulus cucumeris</em> 1 not identified 1 egg</td>
</tr>
<tr>
<td>30.V.2006</td>
<td>Kinderdijk</td>
<td>5</td>
<td><em>Tydeus sp.</em> <em>leafhopper larva</em></td>
<td>32 <em>Amblyseius andersoni</em> 3 <em>Euseius finlandicus</em> 10 eggs</td>
</tr>
<tr>
<td>30.V.2006</td>
<td>Lisse</td>
<td>2</td>
<td></td>
<td>6 <em>Neoseiulus cucumeris</em> 1 not identified</td>
</tr>
<tr>
<td>27.VI.2006</td>
<td>Lisse</td>
<td>10</td>
<td></td>
<td>12 <em>Neoseiulus cucumeris</em> 3 <em>Euseius finlandicus</em> 2 <em>Typhlodromus pyri</em> 5 eggs</td>
</tr>
<tr>
<td>28.VI.2006</td>
<td>Randwijk</td>
<td>5</td>
<td></td>
<td>8 <em>Amblyseius graminis</em> 2 <em>Neoseiulus cucumeris</em> 2 <em>Amblyseius rademacheri</em> 2 not identified</td>
</tr>
<tr>
<td>28.VI.2006</td>
<td>Kinderdijk</td>
<td>10</td>
<td></td>
<td>21 <em>Amblyseius andersoni</em> 1 <em>Euseius finlandicus</em> 5 eggs</td>
</tr>
<tr>
<td>13.VII.2006</td>
<td>Kinderdijk</td>
<td>10</td>
<td></td>
<td>14 <em>Amblyseius andersoni</em> 2 <em>Proprioseiopsis okanagensis</em> 2 <em>Amblyseius rademacheri</em> 1 <em>Amblyseius reductus</em> 1 not identified 1 egg</td>
</tr>
<tr>
<td>3.VIII.2006</td>
<td>Kinderdijk</td>
<td>5</td>
<td><em>Tetranychus urticae</em> <em>3 Thrips sp.</em></td>
<td>2 <em>Amblyseius andersoni</em></td>
</tr>
</tbody>
</table>
Table 1. continued

<table>
<thead>
<tr>
<th>Date</th>
<th>Locality</th>
<th>No. of leaves</th>
<th>Presence of food</th>
<th>Number and species of Phytoseiidae</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.VIII.2006</td>
<td>Kinderdijk</td>
<td>5</td>
<td><em>Tetranychus urticae</em> 4 Thrips sp.</td>
<td>1 <em>Amblyseius isuki</em> 1 egg</td>
</tr>
<tr>
<td>6.IX.2006</td>
<td>Kinderdijk</td>
<td>5</td>
<td><em>Tetranychus urticae</em> 1 Thrips sp.</td>
<td>1 <em>Amblyseius andersoni</em> 1 not identified</td>
</tr>
<tr>
<td>6.XI.2006</td>
<td>Kinderdijk</td>
<td>5</td>
<td></td>
<td>2 <em>Amblyseius isuki</em> 1 <em>Euseius finlandicus</em> 1 not identified</td>
</tr>
<tr>
<td>1.XII.2006</td>
<td>Kinderdijk</td>
<td>20</td>
<td></td>
<td>4 <em>Amblyseius andersoni</em> 1 <em>Neoseiulus cucumeris</em> 1 <em>Euseius finlandicus</em></td>
</tr>
<tr>
<td>1.VII.2007</td>
<td>Kinderdijk</td>
<td>61</td>
<td></td>
<td>55 <em>Amblyseius andersoni</em> 3 <em>Neoseiulus cucumeris</em> 2 not identified</td>
</tr>
<tr>
<td>22.VIII.2007</td>
<td>Kinderdijk</td>
<td>10</td>
<td><em>Tetranychus urticae</em> Tydeus sp. <em>Czenspinskia lordi</em></td>
<td>13 <em>Amblyseius andersoni</em> 2 <em>Proprioseiopsis okanagensis</em> 1 not identified</td>
</tr>
<tr>
<td>9.X.2007</td>
<td>Kinderdijk</td>
<td>10</td>
<td></td>
<td>11 <em>Amblyseius andersoni</em> 1 <em>Euseius finlandicus</em> 1 <em>Amblyseius rademacheri</em> 1 <em>Proprioseiopsis okanagensis</em> 1 <em>Amblyseius graminis</em></td>
</tr>
</tbody>
</table>

Table 2. The overall numbers of predatory mites found on 213 leaves of *Silene dioica* from 2005 to 2007.

<table>
<thead>
<tr>
<th></th>
<th>Kinderdijk 16 samples</th>
<th>Lisse 2 samples</th>
<th>Randwijk 2 samples</th>
<th>Total number</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Amblyseius andersoni</em></td>
<td>211</td>
<td></td>
<td></td>
<td>211</td>
</tr>
<tr>
<td><em>Neoseiulus cucumeris</em></td>
<td>5</td>
<td>18</td>
<td>4</td>
<td>27</td>
</tr>
<tr>
<td><em>Euseius finlandicus</em></td>
<td>7</td>
<td>3</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td><em>Amblyeius graminis</em></td>
<td>1</td>
<td>8</td>
<td></td>
<td>9</td>
</tr>
<tr>
<td><em>Amblyseius rademacheri</em></td>
<td>4</td>
<td>2</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td><em>Proprioseiopsis okanagensis</em></td>
<td>5</td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td><em>Amblyseius isuki</em></td>
<td>3</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td><em>Typhlodromus pyri</em></td>
<td></td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td><em>Amblyseius reductus</em></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Specimens not identified</td>
<td>6</td>
<td>1</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Total number</td>
<td>243</td>
<td>24</td>
<td>18</td>
<td>285</td>
</tr>
</tbody>
</table>

The probability of finding *Amblyseius andersoni* on this hostplant is nearly 100% on this particular location. Knowing such sites for a number of phytoseiid species would be helpful.
for starting laboratory cultures, for refreshing mass-reared populations etc.

In the mild Dutch winters, most of the green parts of the plant deteriorate, but leaves near the ground remain green. *Amblyseius andersoni* was found to overwinter there in low numbers. In Kinderdijk, nightfrost occurred 46 times from 1 January to 6 March 2006. The first phytoseiid eggs were found as early as 30 April 2006.

The predatory mites were not necessarily found on leaves with prey. *Amblyseius andersoni* is a generalist, which preys on spider mites and thrips and has occasionally been observed attacking *Tydeus* sp. and even leafhopper nymphs. Other food sources include pollen from various plants, and fungal spores that are caught and held by the hairy leaves of *S. dioica*.

*Amblyseius andersoni* is the most important native predatory mite on nurseries with hardy nursery stock in The Netherlands, both outdoors and in glasshouses. The species appears to thrive well in heated glasshouses as well as in cooler conditions. It has also been found in samples of strawberry flowers outdoors, probably feeding on thrips larvae.

*Silen dioica* might be used to support the survival of predatory mites on nurseries in order to protect crops such as hardy nursery stock, strawberries and summer cutflowers against various pests. The plants could be planted as a permanent predator reservoir, or placed temporarily as potted plants in the crop. Potted *Ricinus* plants, which were placed temporarily in the crop have been applied by Ramakers and Voet (1996). *Silene dioica* might also support *Feltiella acarisuga* for controlling spider mites, with *Tydeus* sp. as a substitute prey.

References


Natural occurrence and establishment of predatory mites (Acari: Phytoseiidae) on nurseries for amenity trees

Anton van der Linden
Wageningen UR, Applied Plant Research, Bulb Growing, Nursery Stock and Fruit Growing, Lisse, The Netherlands, current address: Wageningen UR Greenhouse Horticulture, P.O. Box 20, 2665 ZG Bleiswijk, The Netherlands, E-mail: anton.vanderlinden@wur.nl

Abstract: Natural occurrence of predatory mites on cultivars of Fraxinus, Tilia, Acer and Carpinus was investigated on 4 nurseries in 2004 and 2005. Amblyseius andersoni (Chant), Euseius finlandicus (Oudemans), Neoseiulus californicus (McGregor) and Typhlodromus pyri Scheuten were the most common species. Occasionally, Phytoseiulus persimilis Athias-Henriot, Neoseiulus cucumeris (Oudemans), Kampimodromus aberrans (Oudemans) and Paraseiulus triporus (Chant & Shaul) were encountered. Releases of Amblyseius andersoni resulted in higher numbers of this predator on Acer platanoides, Tilia platyphyllos and Fraxinus cultivars, but this effect did not persist into the next season. Kampimodromus aberrans was found in high numbers on an older tree of Tilia platyphyllos. After being transferred to nursery trees of the same species, this species was outnumbered by other predatory mites.

Key words: nursery stock, Tilia, Fraxinus, Acer, Carpinus, Phytoseiidae

Introduction

Introducing phytoseiid mites on nursery trees may prevent pest outbreaks during propagation and later on. Twigs from old apple trees are often transferred to newly planted orchards in order to support early establishment of predatory mites, in particular Typhlodromus pyri. If a species is easy to mass-rear, artificial introductions on an industrial scale are an option. An example is Amblyseius andersoni, which is a common indigenous species on many trees and herbaceous plants. It is a generalist preying upon spider mites, gall mites and thrips, all important pests on nursery trees.

On nurseries for amenity trees, spider mites, gall mites and thrips are being controlled with pesticides. The aim of this study (see also van der Linden & Nouwens, 2005) was to survey the species of predatory mites that occur naturally on nurseries with young Tilia spp., Fraxinus spp., Acer plantanoides and Carpinus betulus. Preliminary observations were done on establishing A. andersoni on very young trees after release.

Material and methods

On four nurseries with young trees (Table 1) leaves were collected in 2004 on 3 June, 24 June, 25 August and 21 October and in 2005 on 12 July and 31 August. Sample size was 15 leaves of Fraxinus spp. and 15 or 30 leaves of Tilia spp. and Carpinus betulus. The predatory mites were counted in the laboratory and identified with the help of the descriptions given by Miedema (1987).

A. andersoni from a laboratory rearing was released in the first year on 10 plots. The origin of the culture were specimens collected from Buxus sempervirens in Boskoop in
November and December 2001. Since then, they have been reared with *Acarus* sp. as a substitute prey.

In 2004, high numbers of the predatory mite *Kampimodromus aberrans* (nearly 15 mites/leaf) were found on an older tree of *Tilia platyphyllos* ‘Zetten’. In spring 2005, twigs of this tree were transferred to young trees of the same cultivar on the same nursery.

Table 1. Releases of *Amblyseius andersoni*.

<table>
<thead>
<tr>
<th>Nursery location</th>
<th>Releasing date</th>
<th>Species</th>
<th># of trees</th>
<th># A. andersoni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echteld</td>
<td>3.VI.2004</td>
<td><em>Fraxinus</em> spp.</td>
<td>1,000</td>
<td>18,000</td>
</tr>
<tr>
<td>Opheusden</td>
<td>3.VI.2004</td>
<td><em>Tilia</em> spp.</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Heteren A</td>
<td>3.VI.2004</td>
<td><em>Tilia</em> spp.</td>
<td>1,300</td>
<td>13,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Acer platanoides</em></td>
<td>800</td>
<td>15,000</td>
</tr>
<tr>
<td>Heteren B</td>
<td>6.VII.2004</td>
<td><em>Tilia</em> spp.</td>
<td>1,200</td>
<td>14,500</td>
</tr>
</tbody>
</table>

Results and discussion

*A. andersoni* did establish well on *Fraxinus* spp., *Acer platanoides*, *Carpinus betulus* and on most *Tilia* cultivars. Compared to control plots, predator density was much higher after releases. (Table 2). In October *A. andersoni* was not found on *Fraxinus excelsior* ‘Altena’ anymore, but on *Fraxinus angustifolia* ‘Raywood’ there were still 0.3 *A. andersoni*/leaf present. There were hardly any spider mites present and the numbers of thrips had decreased.

Other indigenous predatory mites occurred naturally, *Euseius finlandicus* in slightly higher numbers than *T. pyri* in 2004. In 2005 *T. pyri* was common on *Tilia platyphyllos* cultivars (Table 3).

Introduction of *K. aberrans* via twigs from an old tree largely failed: only one specimen was recovered on the nursery trees. *E. finlandicus*, *A. andersoni*, *Neoseiulus californicus* and *T. pyri* were more abundant. It seems that young trees of *Tilia platyphyllos* are colonized initially by other predatory mites, and that only after years of succession *K. aberrans* becomes the pre-dominant species on this tree. *K. aberrans* seems to thrive well on trees with hairy leaves, such as *Tilia platyphyllos*, *Corylus avellana* (Miedema, 1987) and on hairy cultivars of *Vitis vinifera* (e.g. Duso, 1992). The predatory mite *Neoseiulus cucumeris* plays a minor role in nursery stock and was not even found in 2005. Only one specimen of *Paraseiulus triporus* was found on *Tilia euchlora*.

*N. californicus* and *Phytoseiulus persimilis* are exotic species, neither of which had ever been released deliberately on these nurseries. *N. californicus* is considered permanently established outdoors in The Netherlands, which is confirmed by these observations. On *Tilia tomentosa* ‘Brabant’ their number reached 1.4 mites/leaf in October 2004. They were less common in 2005, possibly as a result of frost early 2005. Surprisingly, low numbers of *P. persimilis* were found in 2004, but it is not likely that they are able to overwinter.

Predatory mites occurred naturally on trees of all year classes, but were rare on very young trees. Other natural enemies of spider mites and thrips encountered include: *Feltiella acarisuga*, *Stethorus punctillum* and *Orius* spp. They showed up in hot spots or after a period of hot and dry weather, which is profitable for spider mites but not for predatory mites.

Although a variety of predatory mites may occur naturally on nurseries, introduction of *A. andersoni* may help to establish this species on *Tilia* spp., *Fraxinus* spp., *Acer platanoides* and *Carpinus betulus*. On very young trees, hardly any predatory mites are present yet. After
the first winter, the trees are usually cut back, leaving a smooth trunk with few overwintering sites (crevices in the bark). Re-introducing predatory mites when the first leaves have unfolded appears to make sense. Further investigations should reveal the effect of such introductions on the regulation of spider mites, gall mites and thrips later in the season.

Table 2. Total number of predatory mites found on four nurseries in 2004. The leaves were collected on 3 June, 24 June, 25 August and 21 October. Each sample consisted of 15 leaves of *Fraxinus* spp. and 15 or 30 leaves of *Tilia* spp. and *Carpinus betulus*.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Fraxinus excelsior 'Altena'</em></td>
<td>3</td>
<td>1</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><em>Fraxinus excelsior 'Altena'</em></td>
<td>x</td>
<td>12</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Fraxinus excelsior 'Westhof's Glorie'</em></td>
<td>x 19</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Fraxinus angustifolia 'Raywood'</em></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Fraxinus angustifolia 'Raywood'</em></td>
<td>x 23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Carpinus betulus 'Fastigiata'</em></td>
<td>18</td>
<td>3</td>
<td>4</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia europaea 'Pallida'</em></td>
<td>2</td>
<td>8</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia europaea 'Pallida'</em></td>
<td>x 10</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia euchlora</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia euchlora</em></td>
<td>x 16</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia cordata 'Ranco'</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><em>Tilia cordata 'Greenspire'</em></td>
<td>2</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia tomentosa 'Brabant'</em></td>
<td>1</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia tomentosa 'Brabant'</em></td>
<td>x 8</td>
<td></td>
<td>22</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia tomentosa 'Pendula'</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia tomentosa 'Pendula'</em></td>
<td>x 1</td>
<td></td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia platyphyllos 'Zetten'</em></td>
<td>6</td>
<td>9</td>
<td>11</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia platyphyllos 'Delft'</em></td>
<td>3</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia platyphyllos 'Örebrö'</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td><em>Tilia platyphyllos 'Örebrö'</em></td>
<td>x 14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tilia platyphyllos 'Rubra'</em></td>
<td>x 14</td>
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<td>5</td>
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<td><em>Acer platanoides 'Drummondii'</em></td>
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</table>

Acknowledgement

This project was financed by the Product Board for Horticulture (Productschap Tuinbouw), Zoetermeer, The Netherlands.
Table 3. Total number of predatory mites found on four nurseries in 2005. The leaves were collected on 12 July and 31 August. Amblyseius andersoni was released in 2004 only. Each sample consisted of 15 leaves of Fraxinus spp. and 15 or 30 leaves of Tilia spp. and Carpinus betulus.

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References


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Market demands for food safety: perception of a public sale company

Arie van der Linden
The Greenery, Spoorwegemplacement 1, 2991 VT Barendrecht, POB 79, 2990 AB Barendrecht, The Netherlands

Abstract: The Greenery bv is a market-oriented sales company whose shares are owned by the producers who are members of the horticultural cooperative The Greenery U.A.

The 1,350 producer-owned member companies market all their products via The Greenery. The Greenery B.V. is one of the leading concerns in Europe in the vegetable, fruit and mushroom sector. The main activity of The Greenery is to provide a complete range of vegetables, fruit and mushrooms to supermarket chains in Europe, North America and the Far East throughout the year. Other major target groups are wholesale businesses, catering companies and industrial processing companies. Food safety, sustainability, innovation and logistic efficiency have a high priority in all The Greenery’s activities. The company has some 2,500 employees.

Recent developments have put food safety at the top of the consumer agenda. As a response to pressure from consumer and non-governmental groups, retailers have increased their demands on their suppliers. Examples of these increasing demands are the MRL-demands that surpass national and international legislation. To meet these demands, Integrated Pest Management has become a pillar of food safety policy. Arie van der Linden, director Quality and Environment of The Greenery, will elaborate on the changed market demands and the role of IPM. A short overview of recent developments in Dutch horticultural industry is presented focussing on four topics: optimal use of the greenhouse area, maximal utilization of light, reduction of energy use and complete control of the greenhouse environment.
The generalist predator *Typhlodromalus limonicus* (Acari: Phytoseiidae): a potential biological control agent of thrips and whiteflies

Yvonne M. van Houten, Julietta Rothe, Karel J.F. Bolckmans
Koppert Biological Systems, P.O. Box 155, 2650 AD Berkel en Rodenrijs, The Netherlands, E-mail: yvhouten@koppert.nl

Abstract: A strain of the phytoseiid predatory mite *Typhlodromalus limonicus* Garman & McGregor, collected from tomatoes, was tested in a laboratory study as a biological control agent of *Trialeurodes vaporariorum*, *Frankliniella occidentalis* and *Tetranychus urticae*. The following features were tested on cucumber leaf discs: (1) predation and oviposition rate with small *F. occidentalis* larvae as prey, (2) oviposition rates on different juvenile stages of *T. vaporariorum*, (3) oviposition rates on different stages of *T. urticae*. The oviposition rate on young, white eggs of *T. vaporariorum* was also tested on tomato leaf discs. The results showed that *T. limonicus* exhibits a high predation and oviposition rate on a diet of thrips larvae and a high oviposition rate on white eggs, on crawlers and on a mix of the 2nd and 3rd instars of *T. vaporariorum*. The oviposition rate on older, brown eggs of *T. vaporariorum* was much lower. *T. limonicus* produced less eggs on a diet of *T. urticae*. The predator was hampered by the webbing of the spider mites. The oviposition rate on white eggs of *T. vaporariorum* on tomato was significant lower than on cucumber but was still 3 eggs per day. The suitability of this candidate for biological control of whiteflies on tomato remains to be shown in greenhouse experiments.

Key words: *Typhlodromalus limonicus*, *Frankliniella occidentalis*, *Trialeurodes vaporariorum*, *Tetranychus urticae*

Introduction

Western flower thrips *Frankliniella occidentalis* (Pergande), greenhouse whitefly *Trialeurodes vaporariorum* (Westwood), tobacco whitefly *Bemisia tabaci* (Gennadius) and two-spotted spider mite *Tetranychus urticae* (Koch) are major pests in greenhouse crops. The generalist predatory mite *Amblyseius swirskii* is a good biological control agent of both whitefly species and thrips (Bolckmans et al., 2005; Hoogerbrugge et al., 2005) and also feeds on spider mites in sweet pepper and cucumber crops. On tomato crops, however, the predator is less successful due to the glandular hairs on tomato plants (unpublished results). A tomato-adapted predator can improve the control of whiteflies in this crop. Messelink et al. (2006) and Messelink and van Steenpaal (2004) reported that the generalist predator *Typhlodromalus limonicus* (Garman & McGregor) is better than *A. swirskii* as a biological control agent of thrips and whitefly in cucumber. In 2007 a new strain of *T. limonicus*, was collected from tomatoes in New Zealand. We performed a number of small laboratory experiments to assess the potential of this strain as a biological control agent of *T. vaporariorum*, *T. urticae* and *F. occidentalis*. The predation and oviposition rates of *T. limonicus* were tested on a diet of small thrips larvae and its oviposition rate was tested on different juvenile stages of *T. vaporariorum* and on different stages of *T. urticae* on cucumber leaf discs. A small experiment on tomato leaf discs was carried out on a diet of young whitefly eggs to investigate whether *T. limonicus* also produced eggs on tomato leaves.
Material and methods

The strain of *T. limonicus* originated from Crop and Food Research, Auckland and was collected by Peter Workman from beans and tomatoes in New Zealand in 2007. The mites were reared on a diet of cattail pollen *Typha latifolia* and pollen of ice plant *Mesembrianthemum* sp. in a climate room for more than 2 months before testing.

**Predation and oviposition rate on small thrips larvae**

Rates of predation and oviposition on a diet of thrips larvae were determined on discs of cucumber leaves (7 cm²). The leaf discs were placed upside down on pads of moist cotton wool, in a climate room at L16:D8, 25°C and 70% relative humidity. Single gravid female mites were placed on each leaf disc. The mites originated from cohorts of eggs which were reared on pollen. At the start of the experiment the mites had been laying eggs for 2 days. All leaf discs were infested with 12 first instar *F. occidentalis*. During four days the predators were transferred each day to fresh leaf discs with 12 newly emerged thrips larvae. It was ascertained that the number of live prey never dropped below 6 per disc. The number of oviposited eggs and the number of killed thrips were assessed daily. The data of the first day was omitted from calculations.

**Oviposition rate on two-spotted spider mites**

Using the same protocol, gravid female predatory mites were assessed for their oviposition rate when fed with high numbers of spider mites with webbing or with only juveniles of spider mites without webbing on the leaf discs. The cucumber leaf discs (7 cm²) were placed upside down on agar in small ventilated cups. During four days the predatory mites were transferred to fresh leaf discs infested with spider mites.

**Oviposition rate on different stages of whiteflies**

The oviposition rate on whiteflies was measured on cucumber leaf discs (7 cm²) infested with white eggs (0-24 h old), brown eggs (> 72 h old), crawlers or a mix of the 2nd and 3rd instars of greenhouse whiteflies (*T. vaporariorum*). The same protocol was used as in the previous experiment. The oviposition rate on white eggs of *T. vaporariorum* was also measured on small tomato leaf discs.

Results and discussion

The strain of *T. limonicus* used in this study killed on average 6.8 thrips larvae/female/day and produced 3.1 eggs/female/day (Table 1). These high rates are largely similar to those found in the literature for another strain of *T. limonicus* (van Houten et al., 1995).

Table 1. Rates of predation and oviposition of *Typhlodromalus limonicus* on a diet of first instar larvae of *F. occidentalis* on cucumber leaf discs at 25°C. Predation rate: mean number of larvae killed per female per day. Oviposition rate: mean number of eggs laid per female per day. N: number of females; s.e.: standard error.

<table>
<thead>
<tr>
<th>N</th>
<th>Predation rate (mean ± s.e.)</th>
<th>Oviposition rate (mean ± s.e.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>6.8 ± 0.3</td>
<td>3.1 ± 0.1</td>
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</table>
The oviposition rate of *T. limonicus* on spider mites was much lower than on thrips larvae (Table 2). On the leaf discs without spider mite webbing the oviposition rate was 2.8 eggs/female/day whereas on leaf discs with high density of spider mites the oviposition rate decreased to 0.4 eggs/female/day. The predators were adversely affected by the spider mite webbing. The same results are reported for the generalist predators *A. andersoni* (Chant) and *A. swirkii*. These generalists predated two-spotted spider mite but did not enter the webbed colonies (van Houten et al., 2007).

Table 2. Rate of oviposition of *Typhlodromalus limonicus* on a diet of *T. urticae* on cucumber leaf discs at 25°C. Oviposition rate: mean number of eggs laid per female per day. N: number of females; s.e.: standard error.

<table>
<thead>
<tr>
<th>Density of <em>Tetranychus urticae</em></th>
<th>N</th>
<th>Oviposition rate (mean ± s.e.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High density of <em>T. urticae</em> with webbing</td>
<td>8</td>
<td>0.4 ± 0.1</td>
</tr>
<tr>
<td>Juveniles of <em>T. urticae</em> without webbing</td>
<td>13</td>
<td>2.8 ± 0.2</td>
</tr>
</tbody>
</table>

Only few studies regarding oviposition of phytoseiid species on whiteflies have been reported. Swirski and Dorzia (1968) reported an oviposition rate of 1 egg/day/female for *T. limonicus*, when fed on the tobacco whitefly *B. tabaci*. For *A. swirskii*, Nomikou et al. (2003) found an oviposition rate of 2 eggs/female/day on eggs and on crawlers of *B. tabaci*. The oviposition rate on later instars of *B. tabaci* was significant lower. They also found that *Euseius scutalis* produced more eggs on *B. tabaci* than *A. swirskii*. This predator had an oviposition rate of 2-2.5 eggs/female/day on eggs, 2nd and 3rd instars and an oviposition rate of 3.5 eggs/female/day on crawlers of *B. tabaci*.

Table 3. Rate of oviposition of *Typhlodromalus limonicus* on different juvenile stages of *T. vaporariorum* on cucumber and tomato leaf discs at 25°C. Oviposition rate: mean number of eggs laid per female per day. N: number of females; s.e.: standard error.

<table>
<thead>
<tr>
<th>Stage of <em>T. vaporariorum</em></th>
<th>substrate</th>
<th>N</th>
<th>Oviposition rate (mean ± s.e.)</th>
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</thead>
<tbody>
<tr>
<td>white eggs (0-24 h old)</td>
<td>cucumber</td>
<td>23</td>
<td>3.7 ± 0.1</td>
</tr>
<tr>
<td>white eggs (0-24 h old)</td>
<td>tomato</td>
<td>13</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>brown eggs (&gt; 72 h old)</td>
<td>cucumber</td>
<td>10</td>
<td>1.2 ± 0.3</td>
</tr>
<tr>
<td>crawlers</td>
<td>cucumber</td>
<td>14</td>
<td>3.3 ± 0.1 ab</td>
</tr>
<tr>
<td>2nd an 3rd instars</td>
<td>cucumber</td>
<td>9</td>
<td>3.4 ± 0.1 ab</td>
</tr>
</tbody>
</table>

1 Mean followed by the same letters are not significantly different (One-way Anova, \( \alpha = 5\% \)).

In our study *T. limonicus* showed high oviposition rates of 3.7 eggs/female/day on white eggs, 3.3 eggs/day on crawlers and 3.4 eggs/female/day on the 2nd and 3rd instars of *T. vaporariorum* (Table 3) which is better than the results reported for *E. scutalis* on *B. tabaci*. Moreover, all the females of *T. limonicus* tested laid eggs on the 2nd and 3rd instars whereas the percentage of *E. scutalis* and *A. swirskii* preying on later instars decreased (Nomikou et al., 2003). The oviposition rate of *T. limonicus* on brown eggs was significant lower with only 1.2 eggs/female/day. This stage of *T. vaporariorum* seems less vulnerable for *T. limonicus*. Our
results confirm that *T. limonicus* is a promising biological control agent of thrips and whitefly in cucumber.

The oviposition rate on whitefly eggs on tomato leaf discs was significant lower than those on cucumber leaf discs. This indicates that tomato leaves are less favourable than cucumber leaves. However, 3 eggs/female/day on tomato leaves is still very high. Greenhouse trials on tomato will be performed this year to investigate if *T. limonicus* is able to control whiteflies on this crop.

An economic rearing system for *T. limonicus* is still not developed.

**Acknowledgements**

We sincerely thank Peter Workman (New Zealand Institute for Crop and Food Research, Auckland, New Zealand) for his help with collecting *Typhlodromalus limonicus*.

**References**


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Prey preference of the generalist predator *Amblyseius swirskii*

Roos van Maanen, Arne Janssen

*University of Amsterdam, IBED, Institute for Biodiversity and Ecosystem Dynamics, Department of Population Biology, Kruislaan 320, 1098 SM Amsterdam, The Netherlands, E-mail: rmaanen@science.uva.nl*

**Abstract:** Recent research has shown that with a mixed diet of whitefly eggs and first instar thrips, juvenile survival and developmental rate of the predatory mite *Amblyseius swirskii* was significantly higher than on either prey species separately. We studied the prey choice of the mite in a pilot laboratorial experiment in order to detect a preference to uptake of a diet of two different prey species instead of one. Our preliminary results suggest that mites previously fed on whitefly eggs have a preference for first instar thrips larvae. To verify whether this is due to a preference for a varied diet or due to the fact that whitefly eggs are an inferior diet, replication of the experiments and further examination are needed.

**Key words:** prey preference, *Amblyseius swirskii*, biological control, mixed diet, *Frankliniella occidentalis*, *Trialeurodes vaporariorum*

**Introduction**

The practice of biological control demands simple and relatively cheap solutions, for example through using generalist natural enemies that can control several pests simultaneously. However, such use of a single natural enemy for several pest species is not without risk; at a short time scale, an increase in the numbers of one prey species may lead to predator satiation, resulting in decreased predation on the other prey species (so-called apparent mutualism (Holt & Lawton, 1994; Abrams & Matsuda, 1996). Moreover, the prey preference of the predator will determine the population dynamics of the two pest species; when the predator has a strong preference for one of the two pest species, the other species will temporarily experience reduced predation in presence of the preferred pest species. It is therefore important to study prey preference of generalist natural enemies.

The whitefly *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae) and the thrips *Frankliniella occidentalis* (Thysanoptera: Thripidae) are two of the most important pests in greenhouses in Western Europe. Both species cause damage to crops such as cucumber, tomato, sweet pepper, begonia. Recent research has shown that control of the whitefly by the predatory mite *Amblyseius swirskii* was better in presence of thrips than without thrips, but the control of thrips was unaffected by the presence of whitefly (Messelink *et al.*, in press). With the mixed diet of whitefly eggs and first instar thrips, the predators consumed roughly half the numbers of each prey compared to single-species diets, suggesting that the predators have no strong preference for either of the two prey species. We also found that juvenile survival and developmental rate was significantly higher on a mixed diet than on either prey species separately (Messelink *et al.*, in press). We therefore hypothesize that *A. swirskii* prefers a mixed diet when offered a choice and studied the prey choice in a pilot laboratory experiment in order to detect a preference to uptake of a diet of two different prey species instead of one prey species.
Material and methods

Rearings

*A. swirskii* was reared on plastic arenas (8 × 15 cm) placed on a wet sponge in a plastic tray containing water (Nomikou et al., 2003). They were fed cattail pollen, *Typha latifolia* L. twice per week. Western flower thrips and greenhouse whitefly were reared in climate boxes (thrips) or a walk-in climate room (whiteflies) on cucumber plants cv. Aviance RZ, which were grown from seeds in soil in plastic pots (2 l) and kept in a walk-in climate room free of herbivores.

Laboratory experiment

Prior to the experiment a female predatory mite was fed for 2-3 days on a diet consisting of either whitefly eggs, young first instars thrips or a mixture of whitefly eggs and young first instars thrips. These stages are normally attacked by the predators (Nomikou et al., 2004; R. van Maanen, pers. obs.). For the experiment, we used only predatory mites which had just finished feeding on a prey item to ensure that there was no large difference in satiation level between the individuals. Adult female predators (8-12 days old since egg stage) were tested individually on a leaf disc (diam. 24 mm) with 20 whitefly eggs and 4 first-instar thrips larvae. The ratio of 20:4 was chosen because a pilot experiment showed that the two prey types had an equal encounter rate with 20 whitefly eggs and 4 first-instar thrips larvae.

We measured the first choice of the female predatory mites. Mites that did not make a choice within 5½ hours were excluded from the experiment. The behaviour of the predatory mite was recorded during 2-5.5 hours using Etholog 2.2 (Ottoni, 2000). We measured the duration of the following behaviour: searching (i.e., walking), resting (i.e., being immobile), feeding on thrips (i.e., the period during which the mouthparts of *A. swirskii* were inside the thrips), feeding on whitefly eggs (i.e., the period during which the mouthparts of *A. swirskii* were inside the egg). Furthermore, frequencies of encountering thrips or whitefly eggs (touching them) and attacking thrips or whitefly eggs (attempts to subdue them) were registered. We measured the behaviour until the mite started feeding.

Results

Preliminary conclusions are that individuals that had whitefly eggs or thrips larvae as a diet prior to the experiment chose more often for a thrips larvae during the experiment (Figure 1). No difference was found for predators that had previously fed on a mix of thrips larvae and whitefly eggs (Figure 1). In total, eight out of thirteen individuals chose the opposite prey species then the prey fed on previously (Figure 2). This trend is not significant, which is likely due to a lack of repetition.

Discussion

If *A. swirskii* has a preference for whitefly eggs we expect a higher number of mites in all treatments choosing whitefly eggs in the choice experiment. This is not what was found, hence, we can conclude that the mites have no fixed preference for whitefly eggs. If *A. swirskii* has a preference for first instar thrips then we would expect a higher number of mites choosing a first instar thrips. Although we did very few replicates this is what the results suggest. Therefore we can preliminary conclude that the predators have some preference for first instar thrips larvae.
Figure 1. First prey choice of predatory mites that had previously had different diets (Fo = the thrips *F. occidentalis*; Wf = the whitefly *T. vaporariorum*; mix = a mixture of these two prey).

If mites would prefer a mixed diet, we would expect the mites to feed more on the prey that they did not experience before, i.e. mites from a diet of thrips larvae would then choose whitefly eggs, mites from a diet of whitefly eggs would then choose thrips larvae, and mites

Figure 2. Number of individuals that fed on a different prey species as it fed on before the experiment started (opposite) and number of tested individuals that fed on the same prey species as it fed on before the experiment started (same).
from a mixed diet would have no preference. Although we did only 13 replicates, the results so far are mixed: predators that had fed on whitefly eggs seem to have a preference for thrips larvae, but mites that had previously fed on thrips larvae showed no preference for whitefly eggs.

A preference for one or the other species depends on a variety of aspects, such as prey content (Krebs et al., 1978), prey density, toxicity and handling time (Royama, 1970). Moreover, measurements can be influenced not only by preference of the predator but also by anti-predator behaviour of the prey. It is known that predator diet affects the anti-predator behaviour in prey, with predators inducing stronger anti-predator behaviour in prey of the same species that they had previously fed on (Magalhaes et al., 2005). We recorded that the mite fed on the same species as on which it attacked during the experiment in 10 out of 13 replicates. This suggests that anti-predator behaviour did not affect prey choice.

In conclusion our results suggest that mites previously fed on whitefly eggs have a preference for first instar thrips larvae. To verify whether this is due to a preference for a mixed diet or due to whitefly eggs being an inferior diet needs further research.

**Acknowledgements**

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**References**


The release of beneficials in greenhouses with an air blower, a new wind in biocontrol

Jeroen van Schelt, Alex Tetteroo, Hans Hoogerbrugge, Rene Veenman, Karel Bolckmans
Koppert B.V., Veilingweg 17, P.O. Box 155, 2650 AD Berkel en Rodenrijs, The Netherlands, E-mail: jvschelt@koppert.nl

Abstract: A new type of air blower for releasing predatory mites in greenhouse crops has been developed. With this new type air blower predatory mites with a carrier material can be dispersed over the crop up to 5 meters to each side without mechanically damaging the mites. Even distribution of beneficials throughout the crop improves biocontrol in crops like roses, chrysanthemum, and pot plants. Labour costs for distribution biological control agents can be reduced up to 80%.

Key words: release system, fan, ornamental plants, predatory mites, biological control, air blower

Introduction

A uniform distribution of invertebrate biological control agents in a greenhouse crop is an important factor in the success of biological control. Especially non-flying beneficials, like predatory mites, require many release points in a crop. The traditional method to achieve this is to formulate the beneficials with a carrier material, such as vermiculite, saw dust, corn cob grits or bran, and to manually sprinkle the product at many release points throughout the crop. In addition, slow release or breeding sachets have been developed for predatory mites. These sachets contain a small rearing system with bran, astigmatic prey mites and predatory mites. Such a sachet can produce and release large numbers of predatory mites into the crop for several weeks.

However, some practical problems still remain. Sprinkling by hand and introducing sachets is very labour intensive, because one needs to walk throughout the entire crop. Typically about 4,000 release points per hectare are needed, both for sprinkling and introducing sachets. In case of ornamental crops such as chrysanthemums or pot plants on rolling tables or benches it is often hard to reach far enough into the crop or even to walk into the crop as the entire surface is occupied by plants. This limits the use of manual release systems. Another more biological obstacle is that thrips and whitefly are not always easy to control in ornamentals. For the above mentioned reasons, biocontrol in ornamentals is still less far developed when compared to greenhouse vegetables.

With the introduction of the predatory mite Amblyseius swirskii, which preys on whiteflies and thrips, new windows were opened (Bolckmans et al., 2006). Even distribution of these predatory mites and reduction of labour can be achieved by using an air blower. However, most traditional air blowers for releasing beneficials introduce the predatory mites, which are dispersed in a carrier material, into an air stream by means of a venturi pipe. The mites and the carrier material are then accelerated by means of a strong air flow in a plastic or metal pipe. This results in severe damage to the mites because of the strong acceleration and large, harmful shear and friction forces which are inherent to such air blower systems.

With the introduction in 2007 of a new type of air blower to disperse mites with a carrier
material over the crop, a reduction in labour cost of 80% has been achieved. In addition, an almost 100% coverage of leaves can be achieved while maintaining a maximum quality of the predatory mites. These three factors in combination with the newly introduced predatory mite *A. swirskii*, have been responsible for an important step forward in biocontrol in ornamentals. In this article we explain the working principle of this new type of air blower.

**Description of the air blower**

A basic drawing of the air blower is given in Figure 1. The apparatus consists of an outer aluminium frame of $60 \times 40 \times 12$ cm. It holds two state of the art fans. One for blowing to the right and one for blowing to the left. Two plastic dosage containers with a volume of 2 litres contain the beneficial(s) which are formulated in a carrier material. The containers are slowly rotated by means of an electro-motor. The containers have holes from which the beneficials together with the carrier material are gradually dropped into the air stream. This system of gradually dropping the predatory mites into an open air stream is much softer to the mites than the traditional air blower systems.

When developing the air blower, a balance had to be found between blowing far enough into the crop and obtaining an even distribution. The mites, together with the carrier material, can be blown over a distance of 4 to 5 meters in either direction, which results in a total distribution span of 8 to 10 meters. However the first meter was not sufficiently covered. In order to overcome this problem a small hollow pipe is placed in the air stream. This creates a small backwards and downwards airflow which is just hard enough to push down a part of the material to treat the first meter and the area under air blower.

The air blower can move through the greenhouse by means of an electro-motor, which is powered by a rechargeable battery. The transportation system of every air blower is eventually custom made, depending on the greenhouse design. If there are heating pipes above the crop these can be used for hanging the air blower above the crop. For good distribution a minimum distance of 65 cm above the crop is needed. If no pipes are available above the crop, the heating pipes on the ground can be used. In this case the machine is put on a small four wheel driven transport car. The speed can be adjusted in 10 steps from 22 to 40 meter/minute but is preferably set close to its maximum of 40 meter/minute. In both cases the machine is equipped with a sensor to automatically stop at the end of the row and return. Before returning, an extra dosage of beneficials is spread at the end, because this area is only treated once, and also because pest pressure is usually higher at the edges.

The distribution of mites per m² can be calibrated quite precisely by means of the density of mites in the carrier material, the number and size of the holes in the container and the speed of moving the air blower over the crop. Calibration is normally done with the help of a technician and then fixed for future use.

**Types of beneficials used and crops**

In general the machine is used to dispense predatory mites over the crop. *Phytoseiulus persimilis*, *Amblyseius californicus* and *Amblyseius swirskii* are currently the most commonly used beneficials, as a single treatment or in mixtures, depending on the pest problems in the crop. As *P. persimilis* tends to walk upwards in the containers, it is advised to use cooled material and to distribute the mites in the crop early in the morning.

Survival of mites was tested under controlled conditions by placing large white sheets of paper on the ground and recollecting carrier material and predatory mites. It was observed that
the mites were evenly distributed together with the carrier material and were not harmed in any way. This was confirmed by other researchers (Shaw & Wallis, 2007).

In January 2008 in the Netherlands, air blowers are used on approximately 100 hectares, and the area is still rapidly growing. Use per crop is in ranking order: rose (75%), pot plant (15%), and chrysanthemum (10%). To date the best technical results have been obtained in roses. The control of spider mites has been greatly improved by the improved distribution of *P. persimilis* and *A. californicus*. In chrysanthemums biocontrol of spider mites is well established, but thrips control is still a bottleneck.

![Figure 1. General scheme for the air blower. 1. Aluminium frame; 3. Left fan; 4. Right fan; 5. Dosage container for holding beneficials; 6. Holes for releasing beneficials; 7. Motor for rotating dosage container; 8. Hollow pipe to create “backwards” airflow ; 11. Hanging device.](image-url)
Further developments in blower types

The air blower described above can treat 8-10 meters which is sufficient for most greenhouses. However there were demands for air blowers to be used in greenhouses with a width of almost 13 meters. Technically it is not possible to blow that far from one point, because the extra force needed is increasing to the third power with the distance. This problem has been solved by using 4 fans with 4 dosage containers which are connected by a horizontal bar of three meters.

In addition a handheld blower with one fan has been developed. In this case the grower has to walk through the crop and by slowly moving the blower up and down one side of 4-5 meters can be treated. On the way back the other side can be treated. Because in this case the crop is only treated once, more or larger holes in the dosage containers have to be used.

It can be concluded that releasing beneficials by air blowers in a greenhouse meets a demand of the grower to reduce labour costs and yields also better results in biocontrol due to an improved distribution of the natural enemies in the crop. Continuous feedback from the growers will help to improve this system further in the future.

Both types of air blowers are made by Koppert. The automatic air blower is marketed under the trade name AIROBUG and the handheld unit is marketed under the trade name AIRBUG.

A patent has been applied for on both systems (Publication number WO2007136246, Publication date: 2007-11-29).

References


Knowledge transfer of IPM to Finnish ornamental growers in 2004-2007

Irene Vänninen1, Marika Linnamäki2, Pauliina Laitinen1
1Agrifood Research Finland MTT, Plant Production Research, 31600 Jokioinen, Finland, E-mail: irene.vanninen@mtt.fi; 2Biotus Oy, Särkeläntie 6, 30100 Forssa

Abstract: In 2004, a three-year technology transfer project “Integrated Pest Management (IPM) in Ornamental Production” (INTO) was launched in Southern and Western Finland to support greenhouse growers in switching to IPM. In the 25 pilot companies totalling 22 ha, area under IPM doubled during the project. IPM elements included pest monitoring, preventive control, biocontrol and biorational pesticides as part of resistance management. The proportion of pilot companies using biocontrol increased from 31% to 92%. In the end, 54% of the pilot companies were either very satisfied or satisfied with the efficacy of IPM, and 31% were rather satisfied. All pilot companies intended to continue IPM post-project at least in some part of their crop area. The total expenditures – including work input by the staff of pilot companies - to achieve these results was 33966 euros/ha.

Key words: integrated control, biological control, greenhouse ornamentals, knowledge transfer, technology transfer

Introduction

Most innovations penetrate first slowly, followed by a phase of rapid increase of their adoption, which subsequently slows down again (Rogers, 2005). As to IPM in ornamentals, it seems to take about 15 years to increase the percentage of growers using IPM from zero to 30-45% (e.g. Murphy et al., 2002; Carne-Cavagnaro et al., 2005; Korkala, 2005). Over time, technological innovation is communicated through particular channels among the members of a social system through the following stages: exposure to knowledge and understanding of its functions, persuasion (the forming of a favourable attitude to it), decision to commit to adoption, implementation, and confirmation (reinforcement based on positive outcomes) (Rogers, 2005). The successful diffusion of IPM requires the enhancement and expansion of its practitioners’ human capital. On technical matters entailing great complexity or high cost, the recipient has a preference for first-hand, specialised sources of information such as extension experts (Feder & Slade, 1984). This provides the rationale for IPM extension services, grower education programs and various forms of training (Feder et al., 2004).

According to organisational information processing theory (Galbraith, 1974), transfer effectiveness (time and cost) is determined by properly aligning technology uncertainty with the intensity of interaction between the information source and recipient. To ensure successful transfer, information providers should act as facilitators and equal participants in joint learning activities (Hamilton, 2000). Transfer of complex and unfamiliar technology requires the transfer of tacit knowledge. This assumes high information processing abilities and absorptive capacity from the receiving organisation, and emphasizes efficient communication, cooperation and coordination between source and recipient (Stock & Tatikonda, 2000).
Material and methods

INTO-project aimed at increasing the adoption and awareness of IPM among Finnish ornamental growers by contracting 25 pilot companies (private companies and horticultural schools with greenhouse area of 0.1-4.6 ha totalling 22 ha, and with cut roses and flowering potted plants as major crops) that committed to learning about and implementing IPM. The schools’ participation ensured the flow of IPM knowledge to future workforce. The pilot companies were the core units around which the knowledge flows were organised (Figure 1).

Figure 1. Knowledge flows (arrows) in INTO-project. Target groups included both enthusiasts of IPM (lower right picture) and growers at the knowledge capturing stage (left). The former (from pilot companies) usually proceeded quickly to include biocontrol as an element of IPM in their crops. By paying the participatory fee, they took benefit of all knowledge flows. The latter sought knowledge to form an opinion of IPM for their case and attended project events on a case-by-case basis.

The project team’s IPM advisor was responsible for hands-on training and knowledge sharing with the pilot companies. Her approach of “negotiative advising” created a participative learning environment and was clearly welcomed by the participants responsible for implementing IPM. Her own theoretical expertise grew by preparing course and internet materials and was enriched further by learning from practice with the learners implementing IPM. Thus both the knowledge source and receivers learned by doing, and the primary source’s learning was subsequently disseminated to all companies. The advisory service was complemented with general or company-tailored courses on identification, biology and IPM
of key pests and diseases, and resistance management; grower meetings; and seminars which provided platforms for knowledge sharing between all stakeholders. A two-day course emphasising both IPM theory and practice was produced for teachers of horticultural schools. The final seminar was arranged in the form of a Knowledge Market (inspired by the Dutch Strateeg project) six months before the end of the project to ensure that the by then accumulated knowledge was fully available for all participants during the final stages of the project. The Knowledge Market event attracted the interest of TV, radio and newspapers and contributed to informing consumers on the state of art of IPM in ornamental production.

Course materials were fed to the website’s Knowledge Bank (www.agropolis.fi/INTO). Other major knowledge products produced included seven IPM guidelines on planning and implementing IPM in ornamentals; literature reviews on pesticide resistance and side-effects, management of *Bemisia tabaci*, biorational pesticides (oils, soaps, plant extracts, and organosilicone wetting agents with known pesticidal side-effects); and a 28 min. DVD/VHS on the IPM in ornamentals. These products served for and benefited from research elements of the project: efficacy tests of a plan-oil based sticker (Carbon Kick Booster of Carbon Kick Ltd., Pentinmäki, Finland) against two-spotted spider mites, efficacy tests for pesticidal side-effects of an organosilicone wetting agent, behaviour of *Amblyseius swirskii* in gerbera and rose crops in winter months, and developing a database for inputting pest monitoring observations from the crop directly to a hand-held computer. An electronic discussion forum was created at the website, but its use remained low. Face-to-face, e-mail and phone contacts were preferred by the participants seeking support in IPM questions.

The project progress and its impact on pilot companies as a change agent was evaluated by mid-term and end questionnaires. Data on number of plant protection treatments were collected from the pilot and reference (non-IPM) companies for the three project years and 3-5 preceding years to observe potential trends in the use of chemicals.

**Results and discussion**

The companies started IPM and biocontrol trials usually on a small sub-area. The biggest companies were the most careful in allocating area for IPM trials. Of the smaller companies (0.1-0.2 ha), five switched their total area to IPM during the project. A seed of IPM practice was planted in all the companies to serve as an in-company knowledge basis for further expansion. The actual total area under IPM doubled during the project in the pilot companies (Table 1). The majority of pilot companies adopted all central elements of IPM: planning and prevention, monitoring, awareness or use of economic thresholds, and biocontrol as one of the pest management tactics. The rest practiced IPM using preventive control, pest monitoring and biorational pesticides. Economic thresholds developed elsewhere for cut rose pests (Casey & Parrella, 2002) were tried and taken up by some companies. Pest monitoring based on crop inspections as an independent procedure apart from other work tasks increased considerably. Resistance management benefited from the inclusion of biorational pesticides in the spray programs. The plant oil based sticker Carbon Kick Booster was eventually registered as a pesticide owing to the efficacy testings and demonstration trials done in the project. These changes in pest management practices were accompanied by replacement of non-selective pesticides with selective ones, a trend not observed in the non-IPM reference companies. The advisory service, IPM courses and the website were considered the most useful knowledge sources of IPM. In the end, 54% of the pilot companies were either very satisfied or satisfied with the efficacy of IPM, 31% were rather satisfied, 8% were unsatisfied, and 8% could not tell due to recent start of adoption. All pilot companies intended to continue IPM post-project at least in some part of their crop area (Table 1). This is important news for the future of IPM.
expansion in the biggest companies which took the most careful approach in initiating IPM in their area, but which will dominate ornamental production in the future, as the current trend is towards bigger company size due to increasing competition and production efficacy demands.

Table 1. Project impact on the 25 pilot companies’ pest management practices.

<table>
<thead>
<tr>
<th>Attribute impacted</th>
<th>Before</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total area under IPM in ha (% of total area of 22 ha)</td>
<td>3.3 (15)</td>
<td>6.6 (30)</td>
</tr>
<tr>
<td>% companies using IPM on at least part of their area</td>
<td>38</td>
<td>92</td>
</tr>
<tr>
<td>% companies using biocontrol on at least part of their area</td>
<td>31</td>
<td>92</td>
</tr>
<tr>
<td>% companies using seedling inspections before planting</td>
<td>46</td>
<td>54</td>
</tr>
<tr>
<td>% companies using crop inspection as an independent procedure</td>
<td>15</td>
<td>69</td>
</tr>
<tr>
<td>% companies using pheromone traps for pest monitoring</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>% companies practicing pesticide resistance management</td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>% companies using biorational pesticides (oils, soaps etc.)</td>
<td>17</td>
<td>83</td>
</tr>
<tr>
<td>% companies intending to continue IPM on part/whole of their area</td>
<td>62/38</td>
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</table>

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References

Food for thought: how to cater to the nutritional needs of biological control agents?

Felix L. Wäckers
Centre for Sustainable Agriculture, Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, United Kingdom, E-mail: f.wackers@lancaster.ac.uk

Abstract: Predaceous and parasitic arthropods can play an important role in the regulation of herbivore populations. However, the majority of predators and parasitoids also use plant-derived foods as a source of nutrients. This vegetarian side of the menu may include various plant-provided substrates, such as nectar, pollen, or foods indirectly derived from plants (e.g. honeydew). Predators and parasitoids may either use plant-derived food as a supplement, or they may strictly depend on these foods during part of their life. Plant-provided foods can have a dramatic impact on longevity, fecundity, and distribution of predators and parasitoids. Each of these parameters affects herbivore-carnivore dynamics in the field. Modern agricultural systems are characterized by a scarcity of nectar and pollen sources, which can severely compromise the effectiveness of biological pest control. Despite the obvious importance of non-prey food, little is known about the extent to which particular categories of plant-derived foods contribute to the diet of predators and parasitoids under field conditions. Novel technologies allow us to better study the factors that limit survival, dispersal and efficiency of natural enemies under field conditions. These insights will allow us to target these bottlenecks through informed design of cropping systems that address food, prey and shelter requirements of key biocontrol agents.

Is biological pest control limited by food shortages?

Biological control agents are usually identified by their carnivorous lifestyle. Due to this bias, we easily overlook the fact that the majority of these “carnivores” also require nectar, pollen or honeydew as a source of nutrients. Exploitation of these plant-derived foods is widespread among biological control agents from a broad range of orders including Hymenoptera, Diptera, Coleoptera, Heteroptera, Thysanoptera, Neuroptera, Lepidoptera, as well as from the arachnid orders Araneae and Acari. Biological control workers have long suspected that the scarcity of sugar and/or pollen sources in agriculture could impose a serious constraint on the effectiveness of natural enemies in biological control programs (Illingworth, 1921; Hocking, 1966). Hocking (1966) pointed out that lack of food availability could also hamper the establishing of natural enemies in classical biological control programs. Only recently have we started to assess the nutritional status of predators and parasitoids under field conditions (Casas et al., 2003; Lee & Heimpel, 2003; Wäckers & Steppuhn, 2003). Our latest studies confirm that natural enemies can be severely food-deprived in the absence of (suitable) flowering vegetation (Hogervorst et al., 2007a; Olson & Wäckers, 2007). Concurrent studies have shown that the absence of nectar or pollen resources can severely undermine biocontrol efficacy (van Rijn et al., 2006; Winkler et al., 2006).

Requirements for non-prey food

The level in which predators or parasitoids depend on primary consumption varies. Wäckers and van Rijn (2005) distinguish between the categories of ‘life-history omnivores’, ‘temporal
omnivores’ or ‘permanent omnivores’. Life history omnivores include those natural enemies that are strictly dependent on plant-derived food during part of their life cycle, such as hoverflies and many parasitoids. Temporal omnivores supplement their carnivorous diet during part of their life (e.g. host-feeding parasitoids), whereas permanent omnivores retain an assorted diet throughout their lifecycle (e.g. predatory mites and ladybirds). The degree of dependency on non-prey food can vary considerably between omnivorous ‘predators’ with the impact being particularly pronounced in life-history omnivores (see below).

Biological control agents can furthermore be categorized according to the association between prey and non-prey food sources. On the one hand there are those parasitoids and predators whose prey is closely linked to carbohydrate-rich food sources. This applies to species whose prey excretes sugars, e.g. honeydew, or where prey occurs on sugar-rich substrates like fruits or nectar-bearing plant structures. For these parasitoids and predators, locating prey and carbohydrates may represent a single task requiring little or no task differentiation between foraging for prey and non-prey food (Wäckers et al., 2008).

The second group includes those species whose prey is not reliably associated with a suitable carbohydrate source. These species have to alternate their search for prey with bouts of foraging for carbohydrates, which requires a clear task differentiation. Parasitoids from this group often show specific adaptations to the exploitation of both host and nectar resources (Lewis & Takasu, 1990; Wäckers, 1994).

The potential for using food supplements as a tool to raise the effectiveness of biological pest control is determined by the level in which key biological control agents depend on non-prey food, the level of non-prey food available in the system and the suitability of existing food sources. Even predators and parasitoids of honeydew producing pests may benefit from nectar provision (Limburg & Rosenheim, 2001; Robinson et al., 2007), especially during periods of low pest density and in those instances where honeydew has been proven to be a relatively unsuitable sugar source (Wäckers, 2000; Wäckers et al., 2008).

**What’s on the menu? Non-prey food items used by predators & parasitoids**

Predators and parasitoids may feed on various non-prey substrates. The most prominent carbohydrate-rich foods are floral nectar, extrafloral nectar, honeydew, fruits, plant sap, and fungal fluids. Lipid- or protein-rich plant-provided foods include pollen, food bodies, and elaiosomes (Wäckers, 2005). In some cases predators may also feed on plant productive tissue, which classifies them as facultative herbivores (Coll & Guershon, 2002; Eubanks & Styrs, 2005). A few predators exploit a broad range of the above-mentioned food items. This applies especially to ants, which have been the driving force in the evolution of many food-mediated mutualisms (Beattie, 1985). The majority of predators and parasitoids restrict their diet to one or a few alternative foods. Most parasitoid species are restricted to feeding on sugar-rich solutions such as nectar and honeydew. Many predators like hoverflies, lacewings, anthocorid bugs, ladybeetles, and predatory mites feed on pollen as well as nectar/honeydew (Wäckers & van Rijn, 2005). The range of food sources exploited by individual predators and parasitoids under field conditions is likely narrowed by food associative learning (Takasu & Lewis, 1993; Wäckers et al., 2002; Olson et al., 2003).

**Consequences for biological control**

Nectar or pollen feeding by predators can impact predator-prey interactions in a range of ways. While the impact of sugar and pollen feeding is usually positive in terms of predator fitness, there are also mechanisms through which non-prey feeding may interfere with prey
attack rates. This interference can be due to a number of mechanisms: Firstly, there is the fact that time spent searching for-, handling and consuming food is diverted from time available for prey search and handling. In those instances where food foraging requires leaving a profitable prey patch, the time required to find another prey patch following feeding should be considered as well. Satiation constitutes a further mechanism through which nectar or pollen feeding can compromise predation (Lee et al., 2006). When predation rates are limited by gut volume, consumption of non-prey items limits subsequent prey consumption (Hogervorst et al., 2007b). This conflict only applies to temporal or permanent omnivores and not to life-history omnivores such as hoverflies and parasitoids. A possible conflict for all nectar/pollen feeding predators arises when feeding on plant-derived foods induces a period of reduced activity or inactivity. In feeding experiments parasitoids have been observed to consume up to 50% of their body weight of a sugar solution, leaving them incapable of flight over a period of more than 12 hours (Wäckers & Obrist, unpublished). Finally, nectar/pollen foraging may also expose predators to additional risks. These risks may be simply associated with travelling between patches, as movement raises both the exposure to adverse abiotic conditions (wind, rain, drought), passively hunting predators such as web spiders (Völkl & Kraus, 1996) as well as visually hunting predators (e.g. birds). A separate risk category includes specific risks associated with particular feeding sites (Wäckers, 2005).

However, in most instances non-prey food has a positive impact on the fitness of biological control agents and can have a strong impact on pest suppression (Wäckers, 2003; Heimpel & Jervis, 2005; Winkler et al., 2006; Wade et al., 2008). Temporal or permanent omnivores can use (extra-) floral nectar, pollen or honeydew to bridge periods of low prey availability (Limburg & Rosenheim, 2001). Even in presence of excess prey many predators will still consume sugar or pollen on the side, thus underlining the importance of alternative foods. Hogervorst et al. (2007b) showed that lacewing larvae (Chrysoperla carnea) consume honeydew even when the honeydew producing prey is abound. When combined with predation, nectar and pollen feeding can increase predator fitness over prey feeding alone (Porter, 1989; van Rijn & Sabelis, 2005). Life-history omnivores are even more dependent on non-prey food, usually during their adult stage. Their longevity and fecundity are often seriously compromised in the absence of these food sources. This includes the large number of parasitoids that do not engage in host-feeding. At the time of adult emergence, their energy reserves often cover no more than 48 hours of the individual’s energetic requirements. Sugar feeding can increase a parasitoid’s lifespan considerably; up to 20-fold under laboratory conditions (Jervis et al., 1996; Fadamiro & Heimpel, 2001; Wäckers, 2001). In addition, sugar feeding can benefit a parasitoid’s fecundity, not only through an increase in reproductive lifespan, but also through a positive effect on the rate of egg maturation (Jervis et al., 1996). This means that parasitoids that fail to replenish their energy reserves through sugar feeding will suffer severe fitness consequences.

Recent studies employing novel chemical analytical methods to study energetic reserves of field-collected individual parasitoids and predators (Steppuhn & Wäckers, 2004) seem to confirm the earlier suggestions that lack of non-prey food in modern cropping systems may constrain the efficacy of biological pest control (Illingworth, 1921; Van Emden, 1962).

**Three solutions**

Adding suitable food sources to agro-ecosystems could be a simple and powerful tool to enhance the effectiveness of biological control programs. Three types of approaches have been proposed to alleviate the shortage of food in agricultural systems and thus support biological pest control.
**Crop-provided food**

Some crops produce suitable food supplements themselves. Many crops flower during part of their growing period. In crops grown for their seeds or fruits (e.g. cereals, citrus, beans) this flowering period may coincide with the period that the plant is specifically vulnerable to pest attack. Other crops, such as peppers and tomatoes, flower during a large part of the growing season. The availability of floral resources in these crops can contribute to maintaining populations of predatory mites and anthocorid bugs, that can effectively suppress thrips pests (van den Meiracker & Ramakers, 1991). It needs to be noted that tomato flowers are nectariless, whereas pepper flowers provide pollen and nectar.

A number of crops also provide nectar on structures other than flowers. These so-called ‘extrafloral nectaries’ may be found on leaves, stems or fruits. Extrafloral nectaries are generally believed to have evolved as a mechanism for plants to attract sugar feeding carnivores and to draw on their protective services (Turlings & Wäckers, 2004). The fact that extrafloral nectaries have evolved numerous times in nature shows that food supplements are an effective way of enhancing biological control. The extrafloral nectar trait is also found in a number of crops including zucchini, pumpkin, *Prunus* spp. (cherry, plum, peach, almond), cassava, faba bean, and cashew and can be a useful in supporting biological pest control in these crops. The crop-produced nectar may suffice as food sources for predators and parasitoids. In other cases, there may be room for plant breeding to improve the timing, quantity and quality of nectar production, to better match the nutritional needs of biological control agents.

**Artificial food supplements**

When the crop itself falls short in providing nectar and/or pollen, this can be compensated through the use of artificial food supplements such as food sprays (Hagen, 1986; Wade et al., 2008). Artificial food supplements typically consist of a carbohydrate solution in combination with or without a source of protein/amino acids. Insects that utilize honeydew as food source may be especially adapted to exploit this ‘artificial honeydew’. Many studies have identified short term increases in numbers of natural enemies such as parasitoids, lady beetles, lacewings, and predatory bugs as a result of these food supplements (Wade et al., 2008). The impact of food supplements on pest insects varies. While the majority of studies report that food sprays enhance pest suppression, there are some notable exceptions (Wade et al., 2008).

**Diversification of cropping systems**

A third solution to the food shortages in many crops is the introduction of nectar or pollen providing plants. This approach has been widely used in open field systems (van Emde, 1965; Landis et al., 2000; Gurr et al., 2005), but also the use of castor plants (*Ricinus communis*) as a source of extrafloral nectar and excess pollen in protected crops falls under this category. However, not all potential food sources are suitable for a given predator or parasitoid. There is substantial variation between and among food sources with respect to their availability, apparency, accessibility and chemical composition (Wäckers, 2005). While different nectar, pollen or honeydew sources may vary widely, consumers may show an even broader variation with regard to foraging behaviour, mouthpart morphology and physiology. An effective exploitation of food sources requires that there is a suitable fit between consumer attributes and food source characteristics. Identifying and quantifying mechanisms that allow or obstruct successful food source exploitation is not only essential if we want to understand the functioning of food supplements in plant-insect and insect-insect interactions, it also has direct implications for the use of food supplements in biological control programs.
A fly in the ointment: when herbivores benefit from food supplements

Whereas the provision of food supplements is potentially an effective method to enhance biological pest control, the indiscriminate addition of nectar or pollen sources to agro-ecosystems may also backfire. Many arthropod pests are dedicated flower feeders as well (Romeis et al., 2005), and some are more effective in flower exploitation than their natural enemies. When herbivores, rather than their antagonists, gain profit from the available nectar or pollen sources, the net impact on pest control could be negative. This potential problem can be avoided by screening flowers with respect to their suitability for biological control agents (Wäckers et al., 1996; Patt et al., 1997) as well as herbivores (Baggen et al., 1999; Winkler et al., 2003; Wäckers et al., 2007).

Possibilities for selective use of food supplements

We have seen that nectar and pollen sources vary substantially with regard to their suitability as food for particular arthropods. To optimise the impact of food provision in biological control, feeding requirements of both natural enemies and herbivorous pests should be considered when selecting food supplements. Differences in food ecology between both groups can be exploited in selecting flowers that cater for biological control agents, while being unsuitable for herbivores (Baggen et al., 1999; Baggen et al., 2000; Wäckers, 1999; Winkler et al., 2003). The fact that nutritional requirements of natural enemies often differ considerably from those of pest insects can also be used to develop selective food sprays, i.e. food sprays that sustain biological control agents without providing a nutritional benefit to the pest insect (Wäckers, 2001; Romeis & Wäckers, 2002; Winkler et al., 2005).

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Recent progress in IPM and biological control in Japan

Eizi Yano  
Kinki University, Faculty of Agriculture, Entomological Laboratory, Nakamachi 3327-204, Nara 631-8505, Japan, E-mail: yano@nara.kindai.ac.jp

Abstract: I summarise the recent progress in biological control and integrated pest management (IPM) in greenhouses in Japan. Two indigenous predators, the big-eyed bug *Piocoris varius* and a predaceous thrips *Haplothrips brevitubus*, have been tested as new biopesticides of macro-organisms in Japan. Both species are polyphagous predators. *P. varius* can be used for simultaneous control of thrips, aphids and spider mites. *H. brevitubus* can be released to control thrips before the release of *Orius strigicollis*. *H. brevitubus* suppresses the initial increase of thrips and can be consumed by *O. strigicollis* when it starves. A new method using native populations of natural enemies in the field has been developed. *Orius* spp. populations are conserved in the field by planting landscape plants. Special instruments have been developed to collect *Orius* populations in the field and to release them in greenhouses. A banker plant system to establish *Aphidius colemani* has been developed to control *Aphis gossypii* on eggplant in Japan using wheat, barley or oat seedlings infested with *Rhopalosiphum padi* as banker plants. This method can be used for preventive release of natural enemies. Biological control of whiteflies on greenhouse tomatoes is hampered by tomato yellow leaf curl virus (TYLCV) transmitted by *Bemisia tabaci*. Since the whitefly density necessary to transmit TYLCV is very low, farmers do not use natural enemies such as *Encarsia formosa*. Whiteflies are controlled by insect screens, proper use of pesticides and removal of infected tomato plants within and around greenhouses. Whiteflies on tomato plants after harvest are killed by high a temperature treatment involving sealing greenhouses under sunshine.

Key words: biological control, indigenous natural enemy, IPM, TYLCV

Introduction

In 1995, the commercial use of natural enemies in protected crops in Japan was initiated by the registration of *Phytoseiulus persimilis* and *Encarsia formosa*. Seventeen arthropod natural enemies and three insect pathogenic fungi have been registered by 2007. Among these registered natural enemies, five arthropod natural enemies are indigenous species.

Recent research has concentrated on the use of indigenous natural enemies. One reason for this focus is concern about the environmental risks of imported natural enemies. The other reason is that indigenous natural enemies are well adapted to environmental conditions in Japan. In biological control in protected cultures, commercialised natural enemies are released. One problem with the current biological control system is the high price of natural enemies. Another problem is the instability of the effect of natural enemies. Direct use of field populations of natural enemies is one way to cope with their high cost. Inconsistent effects of natural enemies in greenhouses are caused by the death or dispersal of natural enemies when the host or prey density is low. To avoid dispersal or starvation of natural enemies, an alternative host or prey species is necessary. Recent research on biological control in Japan has focused on these points.
Use of new indigenous natural enemies

Piocoris varius
The big-eyed bug Piocoris varius (Uhler) is an indigenous polyphagous predator in Japan, and nymphs and adults were found on 19 plant species (12 families) in a population census in Ibaraki and Chiba prefectures. Based on phenological changes in the field, P. varius is basically univoltine with a partial bivoltine life cycle in these areas (Mukawa et al., 2006).

Control of Frankliniella occidentalis and Aphis gossypii on watermelons by P. varius was tested under greenhouse conditions (Oida & Kadono, 2007; Oida et al., 2007). These pests were controlled effectively by the release of P. varius, which were found on crops throughout the cropping period. P. varius is a promising biological control agent for these pest species, and mass production of this predator with Ephesia kuehniella eggs has been developed.

The effects of plants on the foraging behaviour of P. varius were studied in the laboratory using E. kuehniella eggs as model prey. P. varius consumed significantly more prey eggs on sweet pepper and strawberry than on tomato (Saito et al., 2005). In a feeding site selection experiment using strawberry seedlings, P. varius foraged on the upper compound leaves of seedlings (Saito et al., 2005). The olfactory response of P. varius towards kidney bean leaves infested with T. urticae was studied using an olfactometer. Adult females showed a significant preference for T. urticae-infested leaves over clean air. Second-instar nymphs did not discriminate between T. urticae-infested leaves and clean air (Shimoda et al., 2003). P. varius will be registered as a biopesticide in the near future in Japan.

Haplothrips brevitubus
Haplothrips brevitubus (Karny) is an indigenous predaceous thrips that attacks the mulberry thrips Pseudodendrothrips mori (Niwa) on mulberry trees. This predaceous thrips is easily reared in the laboratory. It is a polyphagous species that attacks thrips, aphids, spider mites, whiteflies, leafminers, broad mites and eggs of Lepidopteran pests. It can feed on flower pollen to reproduce, and its reproductive and predatory capacity is between that of two commercialised predators of thrips, Amblyseius cucumeris and Orius strigicollis. H. brevitubus can be released to control thrips before the release of O. strigicollis. H. brevitubus suppresses the initial increase of thrips and can be consumed by O. strigicollis when it starves. This use of H. brevitubus is helpful for stabilising the effect of O. strigicollis (Kakimoto et al., 2006).

Conservation of Orius spp. in the field to release in greenhouses

O. strigicollis is commonly used to control thrips on eggplant and sweet pepper in greenhouses. One problem, however, is its high price. One solution is to use Orius populations from the field, where they are conserved by planting landscape plants. Verbena (Verbena × hybrida cv. Tapian) and Scaevola aemula were selected to conserve Orius populations in the field (Nagamori et al., 2007), as both plants produce enough pollen and attract flower thrips that serve as food for Orius. Management practices for these plants to conserve Orius populations have been studied. Control of secondary predators that attack Orius spp. is necessary to keep high densities of Orius on plants. Moreover, Orius spp. can reproduce on these plants. Special instruments have been developed to collect Orius populations in the field and release them in greenhouses. The collection instruments can efficiently collect Orius individuals in the field, and the release instrument can release only Orius adults by passing insects through screens of different mesh sizes.
Use of the banker plant system

A banker plant system to establish *Aphidius colemani* has been developed to control *Aphis gossypii* on eggplant in Japan (Nagasaka, unpublished data) using wheat, barley or oat seedlings infested with *Rhopalosiphum padi* as banker plants. This system is put into practice to release *A. colemani* to control *A. gossypii* on eggplant in Kochi Prefecture. Continuous release of parasitoid adults, which is an important characteristic of this method, has a stabilising effect on population fluctuation in the aphid–parasitoid system. In addition, this method can be used for preventive release of natural enemies because they can be produced by alternative hosts on banker plants regardless of the presence of target pests.

Two practical problems hinder the use of the banker plant system for *A. colemani*. One problem is parasitisation by secondary parasitoids. The other problem is that *A. colemani* is effective only against *A. gossypii* and *Myzus persicae*. Another banker plant system using the indigenous strain of the gall midge *Aphidoletes aphidimyza* is being developed. *A. aphidimyza* is more polyphagous and is not attacked by parasitoids.

IPM of TYLCV on tomatoes

Occurrence of the tomato yellow leaf curl virus (TYLCV) was first recognised in Japan in 1996, the year following the registration of *E. formosa*. This virus was transmitted by *Bemisia tabaci* biotype “B” for several years after its first occurrence. Since biotype “Q” was found in 2004, TYLCV has been transmitted by both biotypes. Biotype “Q” is more resistant to insecticides and has wider range of host plants than biotype “B”, which makes it more difficult to control (Honda, 2005).

Whiteflies are controlled by insect screens, proper use of pesticides and removal of infected tomato plants within and around greenhouses. Whiteflies on tomato plants after harvest are killed by a high temperature treatment created by sealing greenhouses under sunshine. Farmers hesitate to use natural enemies because TYLCV is transmitted by whitefly adults at a very low density and because most natural enemies are not effective to control whitefly adults. Biological control of whiteflies is hampered by TYLCV. *B. tabaci* has not shown serious development of resistance to insecticides due to the integrated pest management (IPM) system in Japan. However, the number of effective insecticides against *B. tabaci* is limited, so that integrated use of insecticides and natural enemies seems necessary. Insecticides can be used for direct control of adults that have entered greenhouses. Natural enemies can be used to suppress reproduction of whiteflies in greenhouses.

References


Creating crop solutions in chrysanthemums by using the combined strengths of beneficials and chemicals

Martin Zuijderwijk\textsuperscript{1}, Caroline van den Hoek\textsuperscript{1}, Jan Mostert\textsuperscript{2}
\textsuperscript{1}Syngenta Bioline Ltd, Holland Road, Little Clacton, Essex, CO16 9QG, United Kingdom, E-mail: martin.zuijderwijk@syngenta.com; \textsuperscript{2}Syngenta Crop Protection, Jacob Obrechtlaan 3a, 4611AP Bergen op Zoom, The Netherlands

Abstract: Chrysanthemums are known as a difficult crop for the use of beneficials due to the short crop cycle and low thresholds for pests. Because of the loss of important crop protection products, conventional chemical control of pests has become increasingly difficult. Growers needed to approach crop protection in a different way. Over the last seven years, Syngenta has worked with growers and distributors to create a successful and practical Integrated Crop Management programmes which has resulted in an increase in successful use of beneficials from 5\% in 2003 to 85\% in 2007.

Key words: chrysanthemum, pest, integrated control, \textit{Amblyseius cucumeris}, \textit{Diglyphus isaea}, \textit{Frankliniella occidentalis}, \textit{Liriomyza trifoli}, \textit{Tetranychus urticae}

Introduction

Chrysanthemums have been grown in Holland for decades. Their production is a very intensive and professional year-round business, and covers about 700 hectares. They are grown under artificial light, and annual production reaches over 3 million stems per hectare. The crop cycle takes 10 weeks, and there are multiple overlapping cycles in the glasshouse at any time, so that harvesting is almost continuous. Pests have always been a problem. Growers sprayed weekly to control pests such as \textit{Frankliniella occidentalis}, \textit{Liriomyza trifoli}, \textit{Tetranychus urticae} and \textit{Aphis gossypii}. As a consequence of this regular spraying, chrysanthemums came to be known as the most poisonous flower. Over the last 25 years there has been research to find alternatives, without any reasonable practical success. Growers continued to have problems with spider mite control, and when a key acaricide, Pentac (dienochlor), was withdrawn in 2002, it was only a matter of time before resistance developed to the remaining available products. In addition, growing techniques improved with the use of grow lights. The increased crop density that followed made successful and thorough chemical applications almost impossible. Because of these two problems, Syngenta began trials in 2001 to look at alternative strategies based upon their existing studies with beneficials, in combination with the available chemicals. This approach lead LTO, the chrysanthemum growers’ organisation, to ask Syngenta for help to find a solution to their problems.

Materials and methods

The complex pest situation in chrysanthemums made it impossible to start with just one pest: everything is interlinked, and changing one element has consequences for control of other pests. To solve the spider mite problem it is necessary to solve the thrips and leafminer problem first. Vertimec\textsuperscript{®} (abamectin) was, and will remain, one of the pillars of the chemical programme, and is popular because it controls thrips, leafminer and spider mite. Despite the
short persistence of foliar residues, however, Vertimec is dangerous to predators by direct
treatment, and could not be used once biological controls had been released. Unfortunately,
stopping the use of Vertimec for thrips control to protect the released predators allows
leafminer and spider mite populations to develop, and methods must be found to control them.

Initial field trials during 2001-2002 were done in a 4,000 m² greenhouse. 2,000 m² were
used to test the integrated approach and the remaining 2,000 m² were maintained using a
conventional chemical approach as a comparison. The programme used during each 10 week
crop cycle was divided into 3 parts. In the first 1-2 weeks (start phase) the pest pressure was
minimised by using conventional treatments: the small plants cannot create a humid
environment suitable for establishment of predatory mites. Later treatments give a risk of
chemical residues on the young plants, so the start phase was followed by a ‘growth phase’ of
6 to 8 weeks in which beneficials were used. Because the flowers need to be insect free when
they are harvested, a third (clean-up) phase began two weeks before harvest, during which the
crop can be treated with insecticides if necessary. Following initial successes, the trial area
was expanded to 7 ha in 2002 and 2003, and eventually 18 ha in 2004-2006.

Thrips control
For thrips control, three predators and 4 different release methods were tested in the first year
to see which one gave the best establishment. Orius laevigatus was sprinkled over the crop
with the screens closed, to give semi-darkness and reduce their tendency to fly. Amblyseius
cucumeris was released either by hanging breeding sachets on the wire, or by blowing them
over the crop five times at weekly intervals. The last predator used for thrips control was
Amblyseius montdorensis, which was also sprinkled over the crop. Thrips numbers were
assessed using sticky traps and crop monitoring. 15-20 stems were collected weekly and
washed in 66% alcohol solution to assess predators populations. Based on these field results,
and the economic consequences for practical use, A. cucumeris in breeding sachets was the
method chosen. Even without the alcohol wash results, it was obvious that 6-8 times more
predators were released into the crop by using the sachets (sachets type 2001) than by using
the blowing method. In practical terms, this method was able to control thrips. It was proven
in the greenhouse with a group of growers on 18-hectares of chrysanthemums. Despite the
good technical results there was still a disadvantage: hanging 10,000 sachets a hectare needed
a lot of expensive labour. For this reason alone, and despite the good technical results, the
growers did not accept this method. To solve this labour issue a further product, ‘Bugline cu’,
was developed based upon the patented “Gemini” twin sachet design. Simply described, this
product is a continuous strip of waterproof breeding sachets, which a grower can easily
introduce into the crop using the existing spray boom. This application method saves 75% of
the labour, and the issue is solved.

Leafminer control
This solution for thrips control meant that the only option for leafminer control during the
growth phase was Trigard® (cyromazine), which controls larval stages but is not able to
maintain the very low populations required. Because of these low thresholds, Diglyphus isaea
was introduced weekly during the ‘growth phase’ in summer, and mixed with Dacnusa
sibirica in winter. When leafminers were seen on sticky traps, Trigard® was used to support
the beneficials. As a preventative support, Vertimec was sprayed in the ‘start phase’.
Results and discussion

Thrips

In the first 3 trials in 2001 we were able to find more than 5 \textit{A. cucumeris}/stem in the sachet plot, compared to only 0.45 mites/stem in the blowing area. In the \textit{Orius} plot we found just 0.05 bugs/stem, and 30\% of those we released were found on the sticky traps the days after introduction. Releasing the \textit{Orius} in darkness did not prevent them flying. \textit{A. montdorensis} was also hard to find on the plants, with an average of 0.1/stem. This was partly due to the low numbers released (for cost reasons), and the sprinkling method used for application.

The sachet product, originally developed for vegetables, was adversely affected by the overhead irrigation. Water was sucked up by the edges of the paper and caused mould growth inside the sachets. Once mould growth started, the breeding colony died and sachets no longer produced mites. In addition, the cardboard hooks used became wet, and sachets fell from the wires. In 2004 more than 40\% of the sachets were lost to these two causes, and this reduced the success of the approach. A water resistant package was developed to deal with these problems, and was patented and branded as the ‘Gemini’ sachet. With this improvement we saw significant differences in numbers of mites present on the stems. Figure 1 shows the different numbers of mites/stem using the existing sachet (type 2001) compared with the new ‘Gemini’ type. These figures are not cumulative and are weekly counts. It shows that maintaining a dry formulation in the sachet is critical to breeding capacity. Numbers increased from 2 \textit{A. cucumeris}/stem per week to 28/stem after six weeks. The Gemini sachets were subsequently developed into ‘Bugline cu’ which has a significant labour benefit whilst giving equal or greater numbers of mites on the stems.

![Amblyseius cucumeris on Chrysanthemum stems, 2004](image)

Figure 1. Weekly counts of \textit{A. cucumeris} on chrysanthemum stems. (n = 15).

Thrips damage was often seen in the second week after planting, but no new marks developed on the fresh leaves after the introduction of \textit{A. cucumeris} using this new product. In addition to the effect on thrips, there was also a strong side effect on spider mite. There were fewer problems with spider mite, and therefore fewer acaricides or predators were necessary to
control this pest. Some growers who had thrips and spider mite problems in previous seasons were able to control both pests by using ‘Bugline cu’ only. Thrips control was negatively affected by spider mite populations in some crops. Thrips are known to feed on spider mite eggs, and their presence in spider mite colonies may have protected them from predation by A. cucumeris, or it may be that the availability of an alternative food source reduced predation on the primary target, thrips. Whatever the cause, releases of Phytoseiulus persimilis were needed to control the spider mite.

A. cucumeris also has some limitations as a thrips predator, killing only small thrips larvae. This was especially true in summer, when adult thrips fly into the greenhouse from outside. In this situation, it was crucial to help the A. cucumeris by controlling thrips chemically in the ‘start phase’ and the ‘clean up’ phase. Growers who reduced chemical treatments in the ‘clean up’ phase had bigger thrips problems in subsequent crops. This is in part because the new crop is planted on the same day as the previous crop is harvested. There is no sterilisation, and thrips survive the harvest and new planting either as pupae in the soil or as adults. With low damage thresholds, every surviving adult thrips creates a new problem.

Leafminer
Preventatively introductions of D. sibirica (until March) and D. isaea gave reliable control of leafminers only when supported by Trigard® at the beginning of each crop cycle. Without this, D. isaea took too long to control the leafminer. However, spraying with this product more often than every 5 days substantially delayed the establishment of D. isaea, probably by killing too many leafminer larvae for D. isaea to establish. In winter, when grow lights are on for most of the day, it was difficult to get establishment of D. isaea. Adults of D. isaea and D. sibirica were found dead on the grow lights. Even when the wasps were released in dark conditions at high dose rates of 10/m²/week, leafminer control was poor. Control improved when weekly releases started at the beginning of March. Five releases were made per crop cycle. In crops where no wasps were released, leafminer easily established unless a rigorous series of treatments with Vertimec® and Trigard® were used.

Conclusions
The adoption of an approach drawing upon all available and appropriate solutions has produced a workable and cost effective solution for chrysanthemum growers in the Netherlands. Together with growers and the distributors Brinkman and Van Iperen, Syngenta managed to create an ICM crop programme for chrysanthemums that has resulted in an increase in successful use of beneficials from 5% in 2003 to 85% in 2007. The majority of growers now see Integrated Crop Management as the way forward. Field studies and research to improve the programme will be continued.

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Poster abstracts
A review of thrips (Insecta: Thysanoptera) fauna of ornamental plants in Iran

Valiollah Baniameri, Ebrahim Giliasian
Iranian Research Institute of Plant Protection (IRIPP), P. O. Box: 19395/1454 Tehran, Iran, E-mail: baniameri@yahoo.com

Abstract: A faunistic study was carried out to collect and identify thrips of ornamental plants in Tehran, Markazi and Mazandaran provinces which are located in the north and central parts of Iran during 2002 to 2005. The thrips species were collected from more than 100 species of ornamental plants in greenhouses or in open fields. In this study we report 18 species belonging to the families Thripidae, Aeolothripidae and Phlaeothripidae. We also include the 5 previously recorded species. A total of 23 species, genus Thrips with 7 species had the most diversity and Thrips tabaci was collected in all greenhouses. The collected (18 species) and reported (5 species) are listed as follows:
A: suborder: Tubulifera, Family: Phlaeothripidae: Hoplandrothrips bidens (Bagnall), Haplothrips reuteri (Karney), Haplothrips tritici (Kurdjumov), Haplothrips subtilissimus (Haliday).
Novel products for control of American serpentine leafminer
*Liriomyza trifolii* in greenhouse floriculture

L. Conroy¹, A.B. Broadbent², C.D. Scott-Dupree¹, C.R. Harris¹, G. Murphy³

¹Department of Environmental Biology, University of Guelph, Guelph, ON Canada N1G 2W1, E-mail: lconroy@uoguelph.ca; ²Southern Crop Protection Food Research Centre, Agriculture and Agri-Food Canada, London, ON Canada N5V 4T3; ³Ontario Ministry of Agriculture, Food and Rural Affairs, Vineland, ON Canada L0R 2E0

**Abstract:** The American serpentine leafminer (ASL), *Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae), is a serious pest of chrysanthemum and gerbera daisy in greenhouse floriculture. Growers in Ontario have recently reported decreased ASL control using registered insecticides. Research suggests that this strain of ASL, accidentally imported from the United States on contaminated propagation material, is resistant to both Avid® and Citation®. In light of this insecticide resistance, it is important to develop an effective multifaceted IPM program to control this greenhouse pest. Previous research has suggested that plant anti-desiccants can repel ASL, decreasing both feeding and oviposition. This study investigates the efficacy of two products, Wilt-Pruf® and VaporGard®, as repellents against ASL on chrysanthemum. When given a choice between treated and non treated chrysanthemums, ASL consistently chose non-treated chrysanthemums for feeding and oviposition. Significantly fewer ASL mines developed on treated plants compared to the non-treated plants when ASL was exposed to chrysanthemums for 6 days.
Integrated management of powdery mildew and grey mould of greenhouse pepper in Egypt

Wafaa M. Haggag
Department of Plant Pathology, Division of Agricultural Research and Biology, National Research Center, Egypt

Abstract: Powdery mildew, caused by Leveillula taurica and grey mould caused by Botrytis cinerea are the most important diseases of greenhouse pepper. Various environmentally friendly natural compounds as the biological control agents (BCAs) (Verticillium lecanii, Rhodotorula glutinis and Tilletiopsis minor); mineral salt (phosphate solutions, KH₂PO₄); antitranspirant (kaolin) and antioxidant (ascorbic acid) applied independently or in mixtures as alternatives to chemical fungicides were evaluated for their efficacy in controlling pepper powdery mildew and grey mould in an integrated management system. Application of BCAs, kaolin alone and/or in combination with KH₂PO₄ in vitro to mango leaf disks before inoculation with L. taurica or B. cinerea markedly decreased conidial germination and leaf infection. The largest decrease was obtained with combined treatments. In commercial greenhouse trials during 2005 and 2006 in El-Noubaria naturally infected by powdery mildew and grey mould, each treatment, applied at 15 d intervals effectively controlled L. taurica on leaves and B. cinerea on leaves, fruit and stem. BCAs and kaolin treatments were superior in reducing grey mould infection. Powdery mildew was inhibited by using a mixture of BCAs with or KH₂PO₄. Other tested compounds, such as ascorbic acid as a single treatment or in combination with other compounds showed some effectiveness in reducing powdery mildew and grey mould diseases severity. Mixtures of all four natural compounds were more effective in significantly reducing diseases severity and conidia counts on leaves and fruits and increasing fruit yields than mixtures of two or three or single applications. BCAs, mineral salts, antitranspirant and antioxidant in combinations could be used in an integrated management system to control powdery mildew and grey mould in greenhouse pepper.
**Ceratitis capitata larvae as an alternative food source for Macrolophus caliginosus**

Mauro Nannini¹, Luca Ruiu¹, Ignazio Floris²

¹AGRIS Sardegna, V. le Trieste 111, 09123 Cagliari, Italy, E-mail: laiu@cras.sardegna.it;
²Dipartimento di Protezione delle Piante, University of Sassari, Via E. De Nicola, 07100 Sassari, Italy

Abstract: The suitability of mature larvae of the Mediterranean fruit fly, *Ceratitis capitata*, as an alternative food source for the predatory bug *Macrolophus caliginosus*, was evaluated in comparison with other standard preys. Our experiment results show that this fictitious prey is accepted by all stages of the mirid bug, although specimens reared on fruit fly larvae are not as performing as those reared either on *T. vaporariorum* immatures or *E. kuehniella* eggs. Nevertheless the use of this prey could be envisaged for mass rearing purposes in reason of its low cost.

For the full article please see the Paper Section of this Bulletin.
A novel use of *Ceratitis capitata* for biological control programs

Mauro Nannini, Francesco Foddi, Giovanni Murgia, Riccardo Pisci, Francesco Sanna  
AGRIS Sardegna, V. le Trieste 111, 09123 Cagliari, Italy, E-mail: laiu@cras.sardegna.it

**Abstract:** Fruit flies are currently reared worldwide for IPM purposes (SIT programs, parasitoid rearing). In the present work a novel use of the Mediterranean fruit fly, *Ceratitis capitata*, as food source for *M. caliginosus* is proposed. Quality control tests have shown that the mirid bugs reared on a fruit fly larvae-based diet meet quality standards proposed by IOBC for this beneficial. Individuals fed the fictitious prey exhibit similar predation efficiency to insects reared on the natural prey *Trialeurodes vaporariorum*. On the other hand, the availability of *C. capitata* larvae on tomato plants failed to enhance the establishment of the predatory bug in commercial crops.

*For the full article please see the Paper Section of the Bulletin.*
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The Publication Commission:

Dr. Horst Bathon
Julius Kühn-Institute (JKI)
Federal Research Center for Cultivated Plants
Institute for Biological Control
Heinrichstrasse 243
D-64287 Darmstadt (Germany)
Tel +49 6151 407-225, Fax+49 6151 407-290
e-mail: horst.bathon@jki.bund.de

Prof. Dr. Luc Tirry
University of Gent
Laboratory of Agrozoology
Department of Crop Protection
Coupure Links 653
B-9000 Gent (Belgium)
Tel. +32 9 2646152, Fax +32 2646239
e-mail: luc.tirry@ugent.be

Address General Secretariat:

Dr. Philippe C. Nicot
INRA – Unité de Pathologie Végétale
Domaine St. Maurice – B.P. 94
F-84143 Montfavet Cedex
France


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