



## Interactions between *Orius albidipennis* (Heteroptera: Anthocoridae) and *Neoseiulus cucumeris* (Acari: Phytoseiidae): Effects of host plants under microcosm condition

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### ABSTRACT

In three-dimensional microcosm set-ups we explored the influence of host plant traits of cucumber, eggplant and sweet pepper on the interactions between minute pirate bugs, *Orius albidipennis* (Reuter) and predatory mites, *Neoseiulus cucumeris* (Oudemans) in the presence of extraguild prey, *Thrips tabaci* Lindeman. The host plant influenced the population development of thrips with sweet pepper being most inferior and cucumber being the best for egg laying and/or juvenile development and survival. No host plant effect was found on the survival of adult thrips. The host plant also influenced the biocontrol efficiency of *O. albidipennis* which, on its own, significantly reduced thrips populations on sweet pepper and eggplant, but not on cucumber. A similar host plant effect was not seen for *N. cucumeris* which, on its own, was unable to reduce thrips populations on either of the host plants. No additive or synergistic effect between the two predators was observed. Finally, the host plant influenced the interactions between the two predators—when both predators were present, a significant reduction in the density of adult mites was observed on cucumber and sweet pepper, presumably a result of intraguild predation from *O. albidipennis*. No influence of *O. albidipennis* on the predatory mites was found on eggplant and on none of the host plants was a negative influence observed on mite eggs or nymphs. The results point to the importance of including host plant aspects in studies aimed at evaluations of possible interactions between beneficials intended for simultaneous applications for biocontrol.

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### 1. Introduction

Intraguild predation (IGP) is a common and frequently important interaction in many natural food webs as well as in artificially established communities, e.g. populations of pests and beneficials in crops under biological control (Polis et al., 1989; Polis and Holt, 1992; Rosenheim et al., 1995). In intraguild predation species that compete over a shared (extraguild) prey also engage in predator–prey interactions (Polis and Holt, 1992; Rosenheim et al., 1993) with one species acting as intraguild predator and the other serving as intraguild prey (Rosenheim et al., 1995). In systems where several predators compete for a single dominant prey, intraguild predation is likely to occur (Gardiner and Landis, 2007).

Various factors may influence IGP intensity and outcome, for instance mobility of potential prey, predation strategy, feeding specificity, relative size of opponents, presence of extraguild prey and host plant characteristics such as presence of trichomes, domatia and plant surface waxes (Lucas, 2005). Regarding host plant characteristics Norton et al. (2001) showed that domatia significantly increased survivorships of two beneficial mites in the presence of minute pirate bugs or coccinellids, and Roda et al. (2000) demonstrated the influence of trichome density on the intraguild predation levels on *Typhlodromus pyri* Scheuten (Acari: Phytoseiidae) eggs by the western flower thrips with a significantly reduced IGP on pubescent apple leaves compared to glabrous leaves. Similarly, Lucas and Brodeur (1999) showed that trichomes protected *Aphidoletes aphidimyza* (Rondani) (Diptera: Cecidomyiidae) eggs from intraguild predation by twelve-spotted lady beetles. Not only the characteristics of individual plants but also the vegetation structure may influence IGP as demonstrated by Finke and Denno (2003), who showed that structurally complex habitats dampened IGP by an intraguild predatory spider on its mirid intraguild prey by providing refuges for the latter.

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The effect of intraguild predation on the success of biological control programs has long been controversial (Chang, 1996). Some authors have shown that these interactions may disrupt biological controls (e.g. Rosenheim et al., 1993, 1999; Snyder and Ives, 2001; Finke and Denno, 2003) while others have found that intraguild predators could have a positive effect on biocontrol of pests (Schausberger and Walzer, 2001; Matsumura et al., 2004; Snyder et al., 2004; Gardiner and Landis, 2007). In greenhouse biocontrol, where it has become common practice to apply several species of often generalist natural enemies simultaneously against one or more pest species (e.g. Brødsgaard and Enkegaard, 1997; Meyhofer, 2001; Schausberger and Walzer, 2001; Jakobsen et al., 2002; Meyling et al., 2004), IGP could play an important role for the outcome of control.

Biological control of the important greenhouse pest, the onion thrips *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), is frequently based on simultaneous use of several natural enemies (e.g. Sanchez et al., 2000), including various species of minute pirate bugs (*Orius* sp. (Heteroptera: Anthracoridae)) and predatory mites, especially *Neoseiulus cucumeris* (Oudemans) (Acari: Phytoseiidae) (Riudavets, 1995; Lattin, 1999; Zhang, 2003). IGP between different species of *Orius* and phytoseiid mites has been documented in several studies (Gillespie and Quiring, 1992; Cloutier and Johnson, 1993; Colfer et al., 2003; Brødsgaard and Enkegaard, 2005; Sanderson et al., 2005), as has IGP between *Orius* sp. and other beneficials like *Macrolophus caliginosus* Wagner (Heteroptera: Miridae) (Jakobsen et al., 2004) and *A. aphidimyza* (Christensen et al., 2002).

In a recent study (Madadi et al., 2008) we examined the influence of three host plants (sweet pepper, cucumber, egg plant) on the primarily unidirectional IGP by *Orius albidipennis* (Reuter) on *N. cucumeris* in 2-dimensional laboratory experiments. When extraguild prey (onion thrips) was present, the host plant species had a significant influence the IGP level on adults of the predatory mite, with the level being lowest on the medium trichomed cucumber, intermediate on the densely trichomed eggplant and highest on the smoothed leaved sweet pepper (Madadi et al., 2008). These results were contrary to our expectations, namely that the dense and long trichomes of eggplants would offer the highest degree of protection to the predatory mites or, alternatively, impede the movements of *O. albidipennis*. Our results furthermore showed that only on sweet pepper did the presence of both predators increase thrips mortality above the level inflicted by the predatory mites alone and the resulting combined predation did not differ between host plant species (Madadi et al., 2008). Under practical biocontrol schemes where both beneficials are employed for control of onion thrips the inherent IGP interactions may thus cause a decline in the predatory mite population and consequently result in a thrips biocontrol that is less than additive (sweet pepper) or cancelling out (eggplant, cucumber) (Madadi et al., 2008). However, caution must always be taken when results from small scale laboratory experiments are used to predict interaction outcomes under greenhouse conditions. To further elucidate the practical implications of the host plant aspects in the IGP interactions between *O. albidipennis* and *N. cucumeris* we therefore undertook the present study, applying a 3-dimensional microcosm design to simulate a more realistic and complex habitat structure while keeping the experimental parameters constant (Dinter, 2002; Madsen et al., 2004).

## 2. Materials and methods

All experiments were done on three host plants: *Cucumis sativa* L., cv. Viking, sweet pepper (*Capsicum annuum* L., cv. California Wonder) and eggplant (*Solanum melongena* L., cv. Black Beauty).

These host plants differ, among other things, in the amount, shape and length of the trichomes on their leaves. Sweet pepper is void of trichomes, while the trichomes of cucumber are straight and those of eggplant are umbrella-shaped and entangled (Madadi et al., 2008).

### 2.1. Predators and prey

Onion thrips were reared on bean plants (*Phaseolus vulgaris* L. cv. Montano) in a climate-controlled greenhouse room (25 °C, 60% RH, L16: D8). Predatory mites (reared on mold mites *Tyrophagus purescentiae* (Schrank) (Acari: Acaridae) in bran) were supplied by EWH BioProduction, Tappernøje, Denmark, reared for one generation on onion thrips larvae on cucumber leaves in a cabinet chamber (25 °C, 60% RH, L16: D8) and subsequently used for experiments. *O. albidipennis*, supplied by Bioplanet, Martorano di Cesena, Italy, was collected in 1999 and 2002 from unsprayed open field zucchini, melon and eggplant in southwestern Sicily (Gino Manzaroli, pers. comm.). Upon receipt the bugs were reared on Mediterranean flour moth eggs (*Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) supplied by EWH BioProduction) in ventilated glass jars (height 10 cm, diameter 7.5 cm) with leaves of pilea (*Pilea peperomioides* Diels.) supplied as oviposition substrate. Rearing took place in a climate cabinet at 25 ± 1 °C, 60 ± 5% RH, 16:8 h (L: D).

### 2.2. Experimental procedure

The microcosm consisted of a plant with 2–3 mature non-primary leaves enclosed in a transparent plastic cylinder (∅ 20 cm, height 42 cm) covered at the top with organdie mesh and with two holes (∅ 4 cm) in the side, one covered with mesh for ventilation, the other covered with a moveable lid for introduction of arthropods. The microcosms were placed individually in cages (80 × 75 × 65 cm) placed in a climate-controlled greenhouse room (25° ± 2 °C, 60% RH, L16: D8). The plants were infested with 20 onion thrips females (2–3 days old) and assigned to either control treatment (Tt), treatment with predatory mites (TtNc), minute pirate bugs (TtOa), or both (TtOaNc). For treatments in which predatory mites were included, 10 adult female *N. cucumeris* (3–4 days old) were released in each microcosm 2 days after the thrips infestation. For treatments in which minute pirate bugs were included, 1 adult female *O. albidipennis* (1–2 days old) was released in each microcosm 5 days after the thrips infestation. The predatory mites primarily prey on the first instar thrips larvae with only minor predation on second instar larvae (Bakker and Sabelis, 1986) and no predation on adult thrips. This is in contrast to *O. albidipennis* which easily prey on all thrips stages (e.g. Sabelis and van Rijn, 1997; Deligeorgidis, 2002). Thus a longer access period to the microcosm for the predatory mites was needed to allow their predation to attain proportions comparable to that of *O. albidipennis*.

The experiments were terminated after 9 days when all aerial parts of plants were collected and the number of the different stages of predators and thrips counted. Eggs of *T. tabaci* and *O. albidipennis* were not counted. Each treatment was replicated 10 times.

### 2.3. Data analyses

All data were tested for normality (Bartlett's test, Shapiro-Wilcoxon test) (SAS/STAT, Univariate Procedure, (SAS Institute Inc., 1993)) and for homogeneity of variances (Levene's test) (SAS/STAT, GLM Procedure, (SAS Institute Inc., 1993)). Non-parametric tests (Kruskal-Wallis test) were used when data could not be normalised through transformations.

One-way analysis of variance (ANOVA) was used for analysing the effect of different predator treatments on thrips adult and lar-

val populations using Duncan's test for comparisons of means (SAS/STAT, ANOVA procedure (SAS Institute Inc., 1993)).

### 3. Results

#### 3.1. Thrips density—effect of host plant and predator treatment

The host plant species had a significant effect on the density of thrips larvae in the control treatments (Tt, Table 1) with the lowest density observed on sweet pepper. There was no similar effect of host plants on the density of adult thrips. These results indicate that sweet pepper is a poor host plant for *T. tabaci* egg laying and/or juvenile development and survival, but without adverse effects on the survival of adult thrips.

On sweet pepper and eggplant there was a significant effect on thrips larval densities of treatments including *O. albidipennis* (Table 1) whereas treatment with predatory mites alone did not result in a decrease in larval density compared to the controls (Table 1). However, comparison of the larval densities in the treatments with either of the predators alone (TtNc, TtOa) shows that there was no difference in the efficiency of the predators on these two host plants. In addition, the lack of differences between larval densities in the two treatments with *O. albidipennis* (TtOa, TtOaNc) indicates that any negative interactions (IGP or otherwise) between *O. albidipennis* and *N. cucumeris* were of negligible importance for thrips population development in the present set-up, as well as point to the seeming futility of applying both predators simultaneously. The percentage reduction of the density of thrips larvae compared to the control on eggplant (TtNc: 14.0 ± 6.5%; TtOa: 32.5 ± 9.4%; TtOaNc: 34.1 ± 4.7%) was not significantly different (TtNc: Kruskal–Wallis test:  $\chi^2 = 1.12$ , df = 1,  $P = 0.29$ ; TtOaNc and TtOa:  $T$ -test, df = 18,  $t = -1.20$ ,  $P = 0.245$  resp. df = 18,  $t = -1.41$ ,  $P = 0.175$ ) from that on sweet pepper (TtNc: 29.9 ± 15.1%; TtOa: 50.6 ± 8.8%; TtOaNc: 45.8 ± 8.5%) for either of the treatments indicating that the host plant qualities of these two host plants did not differ in their effect on the efficiency of either of the two predators.

On cucumber none of the predator treatments resulted in thrips larval densities significantly different from the control (Table 1) indicating that *O. albidipennis* on cucumber performed inferiorly compared to the other two host plants. For the treatment with predatory mites alone the percentage reduction of the density of thrips larvae compared to the control (35.6 ± 6.1%) was not significantly different (Kruskal–Wallis test:  $\chi^2 = 3.956$ , df = 2,  $P = 0.138$ )

from that on the other two host plants indicating that cucumber did not affect the mites adversely.

With respect to the effect of predator treatment on thrips adult densities there was no significant influence of the treatment with predatory mites alone (TtNc) (Table 1) which is to be expected since *N. cucumeris* is incapable of attacking the adults (Bakker and Sabelis, 1986). Treatments involving *O. albidipennis*, on the other hand, resulted in significantly lower densities of adult thrips on eggplant and sweet pepper compared both to the controls and to the treatment with predatory mites alone (Table 1). As with the thrips larvae no significant differences were seen in the percentage reduction of adult thrips between eggplant (TtOa: 69.1 ± 8.5%; TtOaNc: 51.9 ± 12.4%) and sweet pepper (TtOa: 60.7 ± 14.9%; TtOaNc: 44.3 ± 8.5%), (TtNc:  $T$ -test, df = 18,  $t = 0.95$ ,  $P = 0.353$ ; TtOaNc: df = 18,  $t = 0.51$ ,  $P = 0.619$ ; TtOa:  $T$ -test, df = 18,  $t = 0.61$ ,  $P = 0.548$ ) indicating that *O. albidipennis* performs equally well on these two plant species. And again no significant differences in adult thrips densities between treatments were found on cucumber supporting the notion that cucumber interfered with the predacious activities on thrips of *O. albidipennis*.

#### 3.2. Predatory mite density—effect of host plant

The host plant species had a significant influence on the density of *N. cucumeris*. In the treatment with just predatory mites (TtNc) this influence was evident for the density of all mite stages with the highest number observed on cucumber and the lowest on sweet pepper (Table 2). However, as stated above, there were no differences between host plant species in the percentage reduction in thrips larval density in the TtNc treatments in relation to control, and the lower mite density on sweet pepper therefore seems merely to reflect the lower thrips density caused by the poor host plant quality of this plant species.

#### 3.3. Interactions between predator species

Comparison of the densities of predatory mites in the treatment with and without *O. albidipennis* shows that the presence of the latter caused a significant reduction in the density of adult mites on cucumber and sweet pepper (Table 2) indicating a negative influence of *O. albidipennis* on *N. cucumeris* adults, presumably in the form of IGP since dead mites showed signs of predation (Madadi personal observation). A similar negative influence of *O. albidipennis* on the predatory mites was not found on eggplant and on none

**Table 1**  
Density of thrips larvae and adults (mean ± SE) on the three host plants in the different treatments.

Host plant	Treatment				Comparison between treatments
	Tt	TtNc	TtOa	TtOaNc	
	<i>Thrips larvae</i>				
Eggplant	201 ± 20.4 <sup>aA</sup>	172.8 ± 13.05 <sup>aAB</sup>	135.6 ± 18.82 <sup>aB</sup>	132.5 ± 9.47 <sup>aB</sup>	$F = 4.14$ , df = 3, 36, $P < 0.05$ $\chi^2 = 7.2$ , df = 3, $P = 0.066$ $F = 4.21$ , df = 3, 36, $P = 0.012$
Cucumber	219.3 ± 26.71 <sup>aA</sup>	141.3 ± 13.35 <sup>aA</sup>	225.33 ± 27.23 <sup>aA</sup>	155.6 ± 18.12 <sup>bA</sup>	
Sweet pepper	64.2 ± 6.96 <sup>bA</sup>	45 ± 9.7 <sup>bAB</sup>	31.7 ± 5.63 <sup>bB</sup>	34.8 ± 5.47 <sup>cB</sup>	
	<i>Comparison of larval densities between host plants</i>				
	$\chi^2 = 19.1$ , df = 2 $P < 0.0001$	$\chi^2 = 19.22$ , df = 2 $P < 0.0001$	$\chi^2 = 21.29$ , df = 2 $P < 0.0001$	$\chi^2 = 19.79$ , df = 2 $P < 0.0001$	
	<i>Adult thrips</i>				
Eggplant	8.1 ± 1.52 <sup>aA</sup>	7.2 ± 0.89 <sup>aA</sup>	2.5 ± 0.69 <sup>aB</sup>	3.9 ± 1.00 <sup>aB</sup>	$\chi^2 = 13.6437$ , df = 3, $P = 0.003$ $\chi^2 = 5.495$ , df = 3, $P = 0.139$ $F = 6.22$ , df = 3, 36, $P = 0.002$
Cucumber	8.2 ± 0.84 <sup>aA</sup>	8.00 ± 0.68 <sup>aA</sup>	6.67 ± 1.05 <sup>bA</sup>	5.8 ± 0.81 <sup>aA</sup>	
Sweet pepper	6.1 ± 1.03 <sup>aA</sup>	6.5 ± 0.91 <sup>aA</sup>	2.4 ± 0.67 <sup>aB</sup>	3.4 ± 0.52 <sup>aB</sup>	
	<i>Comparison of adult densities between host plants</i>				
	$F = 1.03$ , df = 2, 27 $P = 0.37$	$F = 0.81$ , df = 2, 27 $P = 0.456$	$F = 8.81$ , df = 2, 26 $P = 0.001$	$F = 2.48$ , df = 2, 27 $P = 0.103$	

Means with the same upper case letter in a row are not significantly different. Means with the same lower case letter in a column are not significantly different. Treatments: Tt, *Thrips tabaci*; TtNc, *T. tabaci* and *Neoseiulus cucumeris*; TtOa, *T. tabaci* and *Orius albidipennis*; TtOaNc, all three species.

**Table 2**  
Density of the different stages of *Neoseiulus cucumeris* (mean  $\pm$  SE) on the three host plants in the treatments including the predatory mite.

Host plant	Treatment		Comparison between treatments
	TtNc	TtOaNc	
	<i>N. cucumeris</i> eggs		
Eggplant	10.3 $\pm$ 1.47 <sup>abA</sup>	8 $\pm$ 1.89 <sup>aA</sup>	$t = 0.96$ , $df = 18$ , $P = 0.349$
Cucumber	12.9 $\pm$ 2.41 <sup>aA</sup>	8 $\pm$ 2.19 <sup>aA</sup>	$t = 1.5$ , $df = 18$ , $P = 0.15$
Sweet pepper	5.6 $\pm$ 1.36 <sup>ba</sup>	3.4 $\pm$ 1.71 <sup>aA</sup>	$t = 1.49$ , $df = 18$ , $P = 0.153$
	Comparison of mite egg densities between host plants		
	$F = 4.18$ , $df = 2$ , $27$ , $P = 0.026$	$F = 2.52$ , $df = 2$ , $27$ , $P = 0.099$	
	<i>N. cucumeris</i> nymphs		
Eggplant	4.9 $\pm$ 0.87 <sup>aA</sup>	4.3 $\pm$ 1.39 <sup>aA</sup>	$\chi^2 = 1.6$ , $df = 1$ , $P = 0.206$
Cucumber	5.7 $\pm$ 2.1 <sup>aA</sup>	2.9 $\pm$ 0.84 <sup>abA</sup>	$\chi^2 = 0.429$ , $df = 1$ , $P = 0.513$
Sweet pepper	0.9 $\pm$ 0.41 <sup>ba</sup>	1.2 $\pm$ 0.57 <sup>ba</sup>	$\chi^2 = 0.133$ , $df = 1$ , $P = 0.715$
	Comparison of mite nymph densities between host plants		
	$\chi^2 = 11.177$ , $df = 2$ , $P = 0.004$	$\chi^2 = 6.25$ , $df = 2$ , $P = 0.044$	
	<i>N. cucumeris</i> adults		
Eggplant	4.9 $\pm$ 0.43 <sup>abA</sup>	3.6 $\pm$ 0.48 <sup>aA</sup>	$t = 1.42$ , $df = 18$ , $P = 0.173$
Cucumber	5.8 $\pm$ 0.49 <sup>aA</sup>	2.5 $\pm$ 0.7 <sup>abB</sup>	$t = 3.85$ , $df = 18$ , $P < 0.01$
Sweet pepper	3.5 $\pm$ 0.64 <sup>ba</sup>	1.1 $\pm$ 0.38 <sup>bb</sup>	$\chi^2 = 8.03$ , $df = 1$ , $P = 0.009$
	Comparison of mite adult densities between host plants		
	$F = 4.84$ , $df = 2$ , $27$ , $P = 0.016$	$F = 6.04$ , $df = 2$ , $27$ , $P = 0.007$	

Means with the same upper case letter in a row are not significantly different. Means with the same lower case letter in a column are not significantly different. Treatments: TtNc: *Thrips tabaci* and *Neoseiulus cucumeris*; TtOaNc: *T. tabaci*, *N. cucumeris* and *Orius albidipennis*.

of the host plants was a negative influence observed on mite eggs or nymphs (Table 2). There was a significant host plant influence on the difference in the percentage reduction of adult mites between eggplant (26.5  $\pm$  9.7%) and sweet pepper (68.6  $\pm$  10.8%) in treatment TtOaNc compared to treatment TtNc (Kruskal–Wallis test,  $\chi^2 = 6.758$ ,  $df = 1$ ,  $P = 0.009$ ), as well as a tendency to a difference between eggplant and cucumber (56.9  $\pm$  12.1%) (Kruskal–Wallis test,  $\chi^2 = 3.046$ ,  $df = 1$ ,  $P = 0.081$ ).

## 4. Discussion

### 4.1. Thrips density—effect of host plant and predator treatment

The host plant species influenced the population development of *T. tabaci* during the experimental period, with sweet pepper being an inferior host compared to eggplant and cucumber, the latter being the best host. The influence was apparent for the densities of larvae but not for the adult thrips implying that the effect in this case was mediated through an influence on egg laying or on juvenile development and survival. The cause for the poor quality of sweet pepper to *T. tabaci* could be attributable to physical properties, e.g. tough tissue impeding egg laying, or to chemical characteristics, e.g. poor nutritional value. The latter seems plausible in view of the fact that second instar thrips larvae recovered from sweet pepper at the end of the experiment were smaller than those recovered from eggplant and cucumber (Madadi, personal observation).

The results are in agreement with results on intrinsic rate of increase of *T. tabaci* on these host plants reported by Madadi et al. (2006) and imply that successful biological control will be more likely to be achievable on sweet pepper than on eggplant or cucumber where fast population build-ups will quickly lead to the thrips escaping control.

Despite a longer period of presence of *N. cucumeris* (5 days) compared to *O. albidipennis* (3 days) in the experiments the first predator was unable to significantly reduce thrips population relative to the control on either of the host plants. The lack of differences between the host plants is surprising considering the general notion that successful biological control of thrips with *N. cucumeris* can be obtained more easily on sweet pepper than on cucumber and eggplant (Ramakers, 1988; Ramakers et al., 1989;

van Houten, 1996; Messelink et al., 2006) and considering that development of thrips is slowest on this plant species (Madadi et al., 2006) resulting in thrips juveniles being in the first and most vulnerable stage for a long period. However, that the predatory mites were unable to reduce the thrips population even on sweet pepper is in accordance with the results of our previous study with two-dimensional experiments on the same host plants, pest and beneficials (Madadi et al., 2008) where we found that thrips mortality inflicted by adult *N. cucumeris* was highest on the densely trichomed eggplant, intermediate on cucumber, and lowest on the smooth leaved sweet pepper. Trichomes therefore do not seem to provide refuges for the thrips or to impede the movement of the predatory mites (Madadi et al., 2008). In the present experiment the lack of thrips population reduction on sweet pepper may be explained by *T. tabaci* in the eggs stage having a developmental refuge from predation by *N. cucumeris* (which do not prey upon thrips eggs)—egg development of *T. tabaci* on sweet pepper is presumably slowest on sweet pepper compared with the other plant species when judged on the basis of recorded egg development times for *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae) on sweet pepper (3.2 days (Lacasa, 1990)) and cucumber (2.7 days (van Rijn et al., 1995)).

Contrary to the predatory mite, *O. albidipennis* was able to significantly reduce thrips populations on sweet pepper and eggplant, a superiority that can be attributable to its higher voracity (Carl, 1976 stated by Sabelis and van Rijn (1997); Castagnoli and Sauro (1990)) as well as to its ability to prey on all thrips stages (Tommasini, 2003). This result is in agreement with findings for biocontrol of thrips on sweet pepper or eggplant using other species of *Orius* (van de Veire and Degheele, 1992; Dissevelt et al., 1995; Kawai, 1995; Tommasini et al., 1997). However, on cucumber *O. albidipennis* failed to demonstrate this superiority, which presumably is a reflection of, in part, the good host plant quality of cucumber to *T. tabaci* (Madadi et al., 2006) allowing the pest to quickly attain high densities beyond control.

### 4.2. Predatory mite density—effect of host plant

The density of the predatory mite at the end of the experiment was lowest on sweet pepper in terms of all mite stages. This may simply be a reflection of the lower thrips density on this host plant

which, combined with the above-mentioned low predation capacity of *N. cucumeris* on sweet pepper compared to the other two host plants (Madadi et al., 2008), is likely to result in a reduced egg laying or survival of juvenile and adult mites. However, other factors may have played a role such as reduced palatability of thrips larvae produced on sweet pepper; lack of trichomes which the predatory mite tends to use for oviposition substrate (Messelink et al., 2006; Madadi personal observation) or abandonment of the experimental set-up by mites in response to the low prey density.

#### 4.3. Interactions between predator species

Our results demonstrated that the host plant species influenced the interactions between the two predators. Thus in the presence of *O. albidipennis* the density of adult mites at the end of the experiment was significantly lower on sweet pepper and cucumber compared to the adult mite densities in the treatment without the pirate bug (TtNc) whereas no significant interactions could be found on eggplant. Presumably the interactions were in the form of intraguild predation since dead mites showed signs of predation (Madadi, personal observation). However, other types of interactions could play a role for the observed results, e.g. abandonment of the predatory mites from the plant as a reaction to the presence of *O. albidipennis*. The observed negative interaction between *O. albidipennis* and *N. cucumeris* did not result in an increase in thrips densities, presumably a reflection of the experimental period in the present study being too short to allow significant differences (Jansen et al., 2006).

The results are generally in agreement with the findings of Madadi et al. (2008), who in two-dimensional set-ups with detached leaves demonstrated host plant influences on the IGP by *O. albidipennis* on adult *N. cucumeris*. However, the present results differ from the cited study in that the latter also documented the IGP to occur on eggplant and that mortality inflicted by *O. albidipennis* on adult *N. cucumeris* was largest on sweet pepper and least on cucumber (Madadi et al., 2008). The somewhat different results from the present three-dimensional, and thus more complex, set-up are more in agreement with our original expectations that the dense and long trichomes of eggplants would offer the highest degree of protection to the predatory mites or, alternatively, impede the movements of *O. albidipennis* the most. Trichome density has been shown by Roda et al. (2000) to influence intraguild predation levels on *T. pyri* eggs by the western flower thrips with a significantly reduced IGP on pubescent apple leaves compared to glabrous leaves. Other factors besides the physical properties of the host plants may, however, have played a role for the observed results, e.g. thorough plant quality effects on the thrips.

Contrary to the above, no similar interactions were found between *O. albidipennis* and nymphs or eggs of the predatory mite, the latter being in agreement with the study of Madadi et al. (2008), who demonstrated that *O. albidipennis* in the presence of extraguild prey (*T. tabaci*) completely abandoned its IGP on eggs of *N. cucumeris* seen when extraguild prey was absent. It may likewise be that the presence of thrips in the present study caused *O. albidipennis* to refrain from predation on nymphs of the predatory mite, presumably as a result of preference of *O. albidipennis* for the larger and mobile thrips.

Since vegetation complexity has the potential to influence the level of intraguild predation (Finke and Denno, 2002) we increased the complexity of the experimental set-up in the present study beyond the more simple two-dimensional arena experiments we used to document the occurrence of intraguild predation between *O. albidipennis* and *N. cucumeris* (Madadi et al., 2008). The differences found between the two studies in the intensity of the interaction between the two predators and in the influence of host plant species illustrate the importance of temporal and spatial scale. It

remains to be seen through longer-termed and larger-scaled experiments if the interactions documented in this study will also occur to the same extent under conditions mimicking true greenhouse production and if such interactions will in fact have consequences for the outcome of biological control.

## 5. Conclusion

Our study has demonstrated that host plant species influence population development of onion thrips with sweet pepper being the poorer host and cucumber the best. The host plant influence on the pest probably reflected on the population development of *N. cucumeris*. In addition our study has demonstrated host plant influences on biocontrol efficiency of *O. albidipennis* with reduced thrips populations on sweet pepper and eggplant but not on cucumber, presumably reflecting the latter's good host plant quality to thrips. A similar host plant effect on the biocontrol efficiency of the predatory mite was not seen. Finally, our study demonstrated host plant influences in the interactions between the two predators, with predatory mite densities being reduced in the presence of *O. albidipennis* on sweet pepper and cucumber but not on egg plant. The lack of interactions between the predators on eggplant in this study compared to our previous two-dimensional experiments (Madadi et al., 2008) illustrates the need for experiments with a higher degree of spatial complexity to supplement initial and basic laboratory studies. Longer-lasting greenhouse-based studies will be needed for a full evaluation of the biocontrol efficiency of the two predators on the three host plants and of the possible advantages of combining the two predators on the respective host plants in biological control of onion thrips.

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