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Does a supplemental food improve the effectiveness of predatory bugs on cucumber?

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Abstract The objectives of our research were to determine the effect of supplementary food on the dispersion of the predatory bugs *Macrolophus pygmaeus* (Hemiptera: Miridae), *Orius laevigatus* and *O. majusculus* (Hemiptera: Anthocoridae) when released on a pest-infested or non-infested cucumber crop and to evaluate the effectiveness of *O. majusculus*, released together with the addition of supplemental food, on thrips control. The addition of dry *Artemia* sp. cysts as supplemental food to the plant where predators were released did not influence their dispersion from the release plant. Predators dispersed to the infested plants despite the provision of supplemental food on the release patch. In addition, in a greenhouse experiment, predator populations increased quicker when supplemental food was provided, resulting in a better thrips control. Altogether, our results suggest that the addition of supplemental food in the patch where predators are released may be beneficial for pest control in greenhouse cucumber crops.

Keywords *Frankliniella occidentalis* · *Bemisia tabaci* · Factitious prey · Alternative food · Omnivorous predators

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Introduction

The whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) and the thrips *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) are two of the most significant pests in greenhouse cucumber crops (Ramakers and O'Neill 1999). The whitefly produce honeydew, may cause plant weakening and be a vector for several significant viruses (Avilla et al. 2004). Thrips' feeding and/or oviposition in the fruits have been reported to cause cosmetic damage, such as scarring and silvering spots. In addition, they can produce malformations in Dutch-type cucumber fruits that are long, thin-skinned and seedless (Rosenheim et al. 1990; Shipp et al. 2000; Welter et al. 1990).

In Europe and the Mediterranean basin, releases of predatory phytoseiid mites or *Orius* spp. (Hemiptera: Anthocoridae) are used for the biological control of thrips (Castañé et al. 1999; Chambers et al. 1993; Messelink et al. 2006; Ramakers and O'Neill 1999; Shipp et al. 2004). However, broad-spectrum-insecticide-free crops may host significant populations of spontaneously occurring natural enemies, such as *O. laevigatus* (Fieber)*, O. majusculus* Reuter and *Macrolophus pygmaeus* Rambur (Hemiptera: Miridae) (Riudavets and Castañé 1998). Until recently, the latter predator was misidentified as another Miridae species, *M. caliginosus* Wagner (=*M. melanotoma* (Costa)) (Castañé et al. 2013; Martinez-Cascales et al. 2006). All of these predator species are polyphagous and feed on different stages of *B. tabaci* and *F. occidentalis* (Arnó et al. 2010; Castañé et al. 1999).

Orius majusculus is commercially available and it can be an efficient biological control agent against cucumber pests. Compared to phytoseiid mites and other *Orius* species, *O. majusculus* is considered less pollen-dependent (Ramakers and O'Neill 1999), which is particularly relevant because most commercial cucumber varieties are ginoic hybrids, i.e., they only produce female flowers, and therefore do not have pollen. Furthermore, this predator can mainly be found on the leaves, where thrips larvae most often occur (Chambers et al. 1993; Ramakers and O'Neill 1999).

A drawback of using mirid and anthocorid bug predators in biological control is that it may take several weeks until their populations are built up at a level high enough to control the pests, especially at the beginning of the crop's growth when prey are scarce. Longevity and fecundity of these omnivorous predators are clearly enhanced when females feed on prey compared to when they feed on the plant only (Portillo et al. 2012; Pumariño and Alomar 2012). This might be overcome by the addition of supplemental food, such as factitious prey or pollen, to enhance the efficacy of natural enemies, and therefore, contribute to improve biological control of pests (Messelink et al. 2014, Oveja et al. 2012; Perdikis et al. 2011; Put et al. 2012; van Lenteren and Manzaroli 1999). These food resources can be distributed uniformly over the plants or in patches. Since *Orius*, when released into an already established crop, is distributed in foci, food could also be locally provided on these same foci where predators are released. This will enable predators to monopolize the food and reduce the risk that food is used for pest population build up as suggested by van Rijn et al. (2002).

A common practice is the provision of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) eggs, a highly nutritional factitious prey used to feed predators in the commercial mass rearing. However, these eggs are very expensive and other foods may have a similar potential to improve predator reproduction and survival (Riddick 2009). *Artemia* sp. (Branchiopoda: Artemiidae) cysts and bee pollen increase longevity and fecundity of *O. laevigatus*, *O. majusculus* and *M. pygmaeus* and may be good substitutes for *E. kuehniella* eggs (Arijs and De Clercq 2001; Bonte and De Clercq 2008; Castañé et al. 2006; Cocuzza et al. 1997; Perdikis and Lykouressis 2000; Portillo et al. 2012; Vandekerkhove et al. 2009; Vandekerkhove and De Clercq 2010). A possible disadvantage of adding supplemental food in the crop is that, depending on the quantity and quality of the food added, predators might not leave the patch where the food is (van Rijn et al. 2002), and therefore would not disperse into the crop. This would be counterproductive to controlling the pest, because early dispersion and crop colonization by predators were shown to be key elements in their ability to suppress pest populations (Wiedenmann and Smith 1997).

The studies reported in this paper had two objectives. The first was to determine the effect that supplementary food, in this case dry *Artemia* sp. cysts, had on the dispersion of the predators *O. laevigatus*, *O. majusculus* and *M. pygmaeus,* when released on a pest-infested or non-infested crop. The second objective was to evaluate the effectiveness of *O. majusculus* releases and the effect of food supplementation on the control of *F. occidentalis* in a greenhouse cucumber crop.

Materials and methods

Insects and supplemental foods used in the experiments

All insects used in the experiments were reared under controlled conditions at 25 ± 2 °C, 70 ± 20 % RH and a 16:8 h (L:D) photoperiod. All colonies were initiated with field specimens collected in vegetable crops in the Maresme (northeast Spain), except for *F. occidentalis* that were collected in the same area but from geranium flowers. Colonies were periodically refreshed with field specimens.

Macrolophus pygmaeus, *O. majusculus* and *O. laevigatus* were fed with *E. kuehniella* eggs. *Macrolophus pygmaeus* was reared on tobacco plants in aerated cages, whereas *Orius* spp. were maintained in ventilated glass jars (9.5 cm diameter, 14 cm height) and offered green bean pods as oviposition substrate and moisture source. *Frankliniella occidentalis* was also reared in the ventilated glass jars mentioned above and offered green bean pods as food, water source and oviposition substrate. *Bemisia tabaci* rearing was done in aerated cages on cabbage plants (*Brassica oleracea* L. var. Savoy King F1, Sakata Seeds Europe BV). Supplemental foods used in the experiments were non decapsulated dry cysts of *Artemia* sp. with a high unsaturated fatty acid content from Asiatic lakes (INVE Animal Health S.A., Dendermonde, Belgium) and finely ground pellets of dry commercial multifloral bee pollen (Mielar S.A, Barcelona, Spain).

Effect of supplemental food on predator dispersion

The experiment was performed in a plant growth climatic chamber using the controlled conditions mentioned above. Cucumber plants var. Marketer (Semillas Fitó®) were grown from seeds and kept in insect-proof cages in a greenhouse until the first true leaf expanded (approximately 2 weeks). Seven plants were placed in a methacrylate cage (57 × 58 × 48 cm) with side and top ventilation: six plants were situated on the vertices of an equilateral hexagon (48 cm in diameter) and the seventh one on the center of this hexagon, so that the distance between plants was always the same (24 cm). Four treatments were tested: (1) central plant with *Artemia* sp. and surrounding plants infested with thrips (tests with *Orius* spp.) or with whitefly (tests with *M. pygmaeus*), (2) central plant without supplemental food and surrounding plants uninfested, (3) central plant with *Artemia* sp. and surrounding plants uninfested and (4) central plant without supplemental food and surrounding plants infested with thrips (tests with *Orius* spp.) or with whitefly (tests with *M. pygmaeus*). When required, *Artemia* sp. cysts were supplied glued onto 2 cm^2 areas of a Post-it® (0.008 ± 0.0002 g cm^{-2}, n = 5). To infest plants with *F. occidentalis*, 3–4 days before the experiment the plants were placed in a separate cage and 20 thrips larvae per plant were added. To infest plants with whitefly, cucumber plants were placed in the *B. tabaci* rearing cages for 2 h to allow for egg laying, and then the plants were removed and placed in another cage for 24 h until the beginning of the trial.

Twenty female predators (age 1–7 days) were placed inside a vial and then carefully released on the central plant of each cage by unplugging and gently tapping the vial. The presence of predators on the surrounding one leaf cucumber plants was recorded every hour, for a total period of 6 h. The frequency of observations was set according to Venzon et al. (1999), who observed that the minimum residence time of *O. laevigatus* on a clean cucumber plant was longer than an hour. In each observation, all predators that were on the surrounding plants were carefully removed with a mouth-aspirator to ensure that they did not interfere by attracting or repelling predators that had not yet dispersed (Janssen et al. 1997, 1998). At the end of the 6 h period, the number of predators present on each of the seven plants inside the cage was counted separately. Each treatment was replicated ten times.

Effect of *O. majusculus* and supplemental food on *F. occidentalis* control

The trial was carried out in a plastic greenhouse (430 m^2) divided into twelve large exclusion cages (6.40 × 4.50 m) with a fine plastic net of 10 × 20 gauge mesh in order to prevent insect movement between compartments. Each cage had four standard coconut fiber growbags (two bags per row) and two cucumber plants per bag, with a total of eight plants per cage that were transplanted on June 5, 2009. A Dutch-type cucumber cultivar Estrada (Semillas Fitó®) was used because the fruits of these varieties are highly susceptible to *F. occidentalis*. Plants were tied to strings, pruned as needed and maintained on a fertigation system. The temperature and RH were monitored using a digital data recorder (Hobo, Onset Computer Corporation, Massachusetts, USA), placed at 2.15 m above the ground in the middle of the greenhouse.

Four treatments were tested using a randomized complete block design with each treatment replicated three times. The treatments were: (1) *F. occidentalis* + *O. majusculus*, (2) *F. occidentalis* + *O. majusculus* + *Artemia* sp., (3) *F. occidentalis* + *O. majusculus* + *Artemia* sp. + pollen, (4) control treatment with only *F. occidentalis*. Seventeen days after transplant 22 second-instar thrips larvae were placed on each plant. The day after, when appropriate, a male and a female *O. majusculus* were released on each plant and *Artemia* cysts (0.1 g $plant^{-1}$) or *Artemia* cysts plus pollen (0.1 + 0.1 g $plant^{-1}$) were added directly on the leaves.

Starting the week after *O. majusculus* release, five weekly samplings were done on four randomly selected plants per cage. Each plant was sampled by randomly selecting three leaves: one from the top, one from the middle and one from the bottom of the cucumber plant. The number of *O. majusculus* adults and nymphs and the number of *F. occidentalis* adults and larvae were counted with the naked eye on each leaf. From July 24th to August 6th, fruits were harvested on four occasions, scoring the total number of fruits per cage, fruit weight and number of fruits that had cosmetic damage (silvering spots and scarrings) caused by *F. occidentalis* feeding on fruit.

Statistical analysis

To test the effect of supplemental food on the predators' dispersion, a two-way ANOVA (addition or not of supplemental food on the central plants and infested vs. uninfested surrounding plants) was used to compare the number of predators remaining on the central plant at the end of the experiment and the cumulative number of predators on the surrounding plants at each sampling. In both analyses raw data were used for *O. laevigatus* and *M. pygmaeus*, whereas data for *O. majusculus* were transformed by log (x + 1) and by $\sqrt{(x + 0.5)}$, respectively, to homogenize variances. Raw data are presented in tables and figures.

In the greenhouse trial, to assess the effect of *O. majusculus* and supplemental food on *F. occidentalis* control, all insect and fruit parameters evaluated were analyzed using a two-way ANOVA in a randomized complete block design. Only F and *P* values of the treatment comparisons are presented. The parameters analyzed were: cumulative insect-days, total fruit weight, total fruit number and total number of fruits with cosmetic damage. Cumulative insect-days were calculated according to Ruppel's (1983) method by using the average number of *F. occidentalis* (adults and larvae) and *O. majusculus* (adults and nymphs) per plant. Number per plant was obtained as the mean insect counts on the three leaves sampled at each date.

In all tests, significant differences between means were identified by a Tukey's test ($P < 0.05$). The data were statistically processed using the SAS Enterprise Guide 4.2 program.

Results

Effect of supplemental food on predator dispersion

When analyzing the effect of a supplemental food in the release patch on the dispersion of *O. majusculus*, *O. laevigatus* and *M. pygmaeus* (Fig. 1), the presence of *Artemia* sp. did not influence the number of predators remaining on the release plant at the end of the experiment: $F_{1,36} = 0.19$, $P = 0.669$ (*O. laevigatus*); $F_{1,36} = 0.03$, $P = 0.855$ (*O. majusculus*); $F_{1,36} = 0.08$, $P = 0.783$ (*M. pygmaeus*). In contrast, the presence of pests on the surrounding plants (Fig. 1)

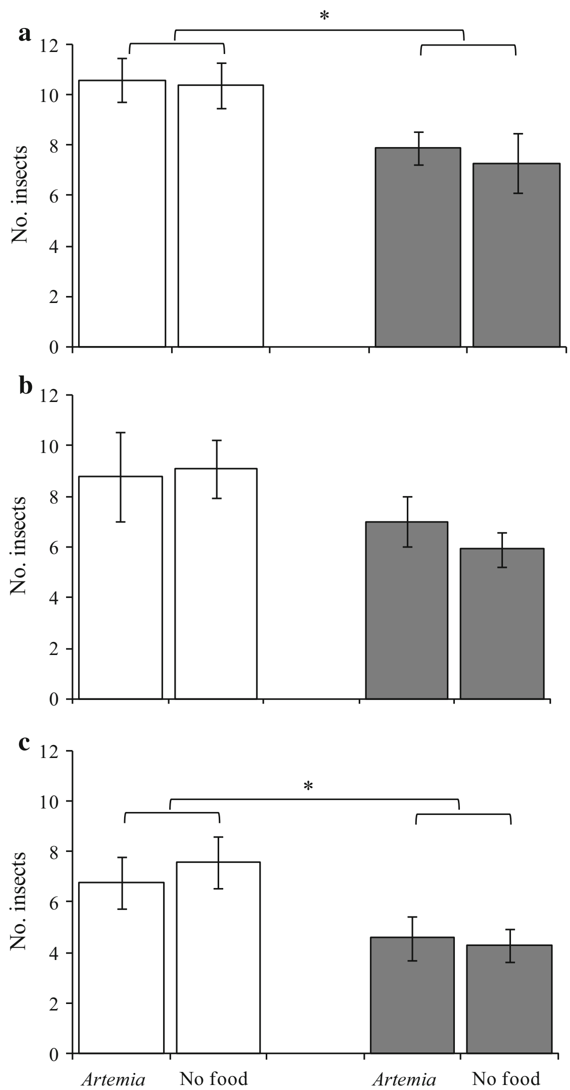

Fig. 1 Mean number (±SE) of *O. laevigatus* (**a**), *O. majusculus* (**b**) and *M. pygmaeus* (**c**) on the central plant where they were released, depending on whether *Artemia* sp. cysts were present on this plant or not and whether surrounding plants were uninfested (*empty bars*) or infested (*solid bars*). Observation was done 6 h after the predators were released on the central plant. Significant differences ($P < 0.05$) between infested and uninfested surrounding plants are marked with an *asterisk*

did significantly influence the number of *O. laevigatus* and *M. pygmaeus* that remained on the release plant at the end of the experiment (*O. laevigatus*: $F_{1,36} = 9.77$; $P = 0.004$; *M. pygmaeus*: $F_{1,36} = 9.31$; $P = 0.004$), being higher when surrounding plants were uninfested. On the contrary, the thrips' presence on the surrounding plants did not have a significant effect on the number of *O. majusculus* that, at the end of the experiment, remained on the central plant where they were released ($F_{1,36} = 2.32$; $P = 0.136$).

When studying the process of colonization of the surrounding plants, no significant differences were observed between treatments with and without *Artemia* sp. cysts on the release point (Table 1). In contrast, the presence of *B. tabaci* and *F. occidentalis* on the surrounding cucumber plants did have a positive effect on colonization and predators dispersed faster in treatments with infested plants than with uninfested plants. As observed in Fig. 2, 1 h after *O. laevigatus* and *O. majusculus* were released, surrounding plants hosted a significantly higher number of predators when they were infested than if they were uninfested. This difference was maintained during the whole experiment (6 h). A positive effect of *B. tabaci*-infested plants was also observed with the colonization of *M. pygmaeus*. However, this effect was not significant up to four hours after the predators were released.

Effect of *O. majusculus* and supplemental food on *F. occidentalis* control

The inoculation of *O. majusculus* alone or together with the addition of supplemental food significantly reduced *F. occidentalis* infestation in cucumber plants (Table 2). In the first two samplings, conducted 1 and 2 weeks after predator release, the thrips population was significantly lower in the treatment with *O. majusculus* and cysts of *Artemia* sp. than in any of the other treatments. From the second count (July 7) and until the end of the experiment, *F. occidentalis* populations were significantly lower in all treatments with *O. majusculus* compared to the control without predators. Furthermore, in these samplings, lower thrips infestations were always recorded in the treatments with supplemental foods, except in the last count, conducted on July 29, when significant differences were only shown between the treatment with just *O. majusculus* and the treatment with predator +*Artemia* sp. cysts + pollen.

The predator *O. majusculus* was able to reproduce and become established in the crop and growing populations were recorded in the course of the experiment, especially in both treatments with supplemental foods (Table 2). When we consider the predator population dynamics in terms of cumulative insect-days during the period from July 7 to July 21, providing only *Artemia* sp. cysts as supplemental food

Table 1 Results of the two-way ANOVA comparing the number of predators on the surrounding plants, depending on whether supplemental food was present on the plant where predators were released and whether surrounding plants were uninfested or infested during the experiment

Time after predator release	*O. laevigatus*		*O. majusculus*		*M. pygmaeus*	
	F	*P*	*F*	*P*	*F*	*P*
Factor: supplemental food presence						
1 h	0.55	0.464	0.50	0.485	0.17	0.679
2 h	0.15	0.702	0.20	0.656	0.27	0.606
3 h	0.09	0.771	0.07	0.799	0.01	0.919
4 h	0.48	0.495	0.01	0.929	0.06	0.808
5 h	0.07	0.791	0.02	0.886	0.00	0.962
6 h	0.24	0.627	0.09	0.762	0.02	0.898
Factor: pest infestation on surrounding plants						
1 h	6.33	0.017	11.84	0.002	1.94	0.173
2 h	20.30	<0.001	13.80	<0.001	1.56	0.220
3 h	19.29	<0.001	19.06	<0.001	3.75	0.061
4 h	15.74	<0.001	27.84	<0.001	6.25	0.017
5 h	23.90	<0.001	19.62	<0.001	10.96	0.002
6 h	49.45	<0.001	24.23	<0.001	10.91	0.002

Degrees of freedom of all analyses: 1, 36

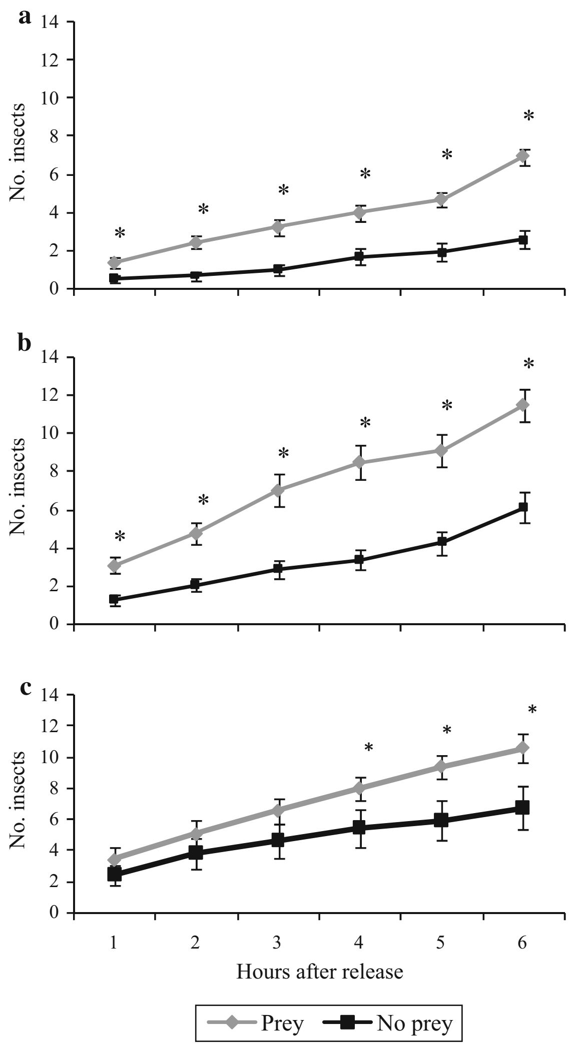

Fig. 2 Cumulative number of insects (mean ± SE) for *O. laevigatus* (**a**), *O. majusculus* (**b**) and *M. pygmaeus* (**c**) on the surrounding cucumber plants for the samplings conducted 1, 2, 3, 4, 5, and 6 h after predator release. Significant differences ($P < 0.05$) among treatments are marked with an *asterisk*

significantly increased the *O. majusculus* population compared to when providing *Artemia* sp. and pollen (Table 2). However, in the last count, conducted on July 29, no significant differences were found in the predator population on plants of the treatments *Orius* + *Artemia* cysts and *Orius* + *Artemia* cysts + pollen.

Regarding fruit damage by *F. occidentalis*, no significant differences were found in terms of production (total number of fruits produced and total yield weight) nor in the number of fruits with cosmetic damage (Table 3): $F_{3,6} = 0.44$; $P = 0.733$ (total number of fruits produced), $F_{3,6} = 0.92$; $P = 0.486$ (total yield); $F_{3,6} = 4.02$; $P = 0.070$ (number of damaged fruits). Nevertheless, the number of fruits with cosmetic damage was numerically higher in the treatment without predators than in treatments where *O. majusculus* specimens were released. The lowest number of damaged fruits was recorded in the treatment where *Artemia* and pollen were added.

Discussion

The results presented in this paper show that the addition of dry *Artemia* sp. cysts as supplemental food to the plants on which *M. pygmaeus*, *O. laevigatus* and *O. majusculus* were released did not inhibit their dispersion from these release plants. After 6 h, less than 50 % of the predators remained on the central plant. In contrast, the presence of the herbivore on the surrounding plants did have a positive effect on the colonization process of the predators. *Orius laevigatus*, *O. majusculus* or *M. pygmaeus* dispersed quicker from plants on which they were released, whether or not supplemental food was present, to plants infested with *F. occidentalis* or *B. tabaci* than to uninfested plants. In the 6 h experiment, between 15 and 35 % of the released insects reached the uninfested surrounding plants, whereas these percentages were 35–60 % when infested plants surrounded the release plant. Higher numbers of females of the two *Orius* species colonized plants infested with thrips from the very beginning. However, whitefly presence did not stimulate the colonization of surrounding plants by *M. pygmaeus* so fast. This could be explained by the fact that *M. pygmaeus* is a more energy-conservative species than is *O. majusculus*, which is a more actively searching predator (Montserrat et al. 2004).

It has been demonstrated that a predator's success in finding prey is related to its ability to recognize volatiles that are released by plants damaged by herbivores (Dicke 1994; Pallini et al. 1997; Tumlinson et al. 1993). The faster *Orius* spp. colonization of thrips-infested plants compared to the *M. pygmaeus* colonization of *B. tabaci* infested plants may have been influenced by the different types of damage that both herbivores inflicted on the plants. It is known that the emission of plant volatiles is relatively specific to the type of insect feeding (Turlings et al. 1990). Insects, such as *B. tabaci* nymphs, that feed on

Table 2 Cumulative number of insect-days (mean ± SE) of *F. occidentalis* (adults + larvae) and *O. majusculus* (adults + nymphs) in each treatment for the five sampling dates and results of the two-way ANOVA

Treatment	June 30	July 7	July 14	July 21	July 29
F. occidentallis					
Fo	425.3 ± 100.46a	962.8 ± 75.83a	1451.7 ± 67.82a	2003.5 ± 133.29a	2614.3 ± 127.80a
Fo Om	380.0 ± 96.03a	755.5 ± 61.66b	943.3 ± 33.59b	1151.0 ± 36.43b	1260.8 ± 23.59b
Fo Om ART	178.7 ± 25.54b	334.3 ± 20.64d	641.2 ± 56.66c	857.0 ± 48.62c	1061.5 ± 40.46bc
Fo Om ART POL	393.3 ± 69.83a	563.3 ± 22.26c	722.0 ± 21.86c	825.8 ± 20.74c	994.8 ± 42.73c
F	9.63	84.23	274.29	116.40	253.52
df	3, 6	3, 6	3, 6	3, 6	3, 6
P	0.010	<0.001	<0.001	<0.001	<0.001
O. majusculus					
Fo Om	24.0 ± 4.62a	48.0 ± 4.62b	72.0 ± 4.62c	120.5 ± 14.72c	192.7 ± 15.07b
Fo Om Art	26.7 ± 7.06a	82.7 ± 14.01c	152.5 ± 12.99a	252.7 ± 23.12a	364.5 ± 21.07a
Fo Om Art Pol	24.0 ± 4.62a	48.0 ± 4.62b	104.7 ± 14.77b	205.7 ± 22.84b	344.0 ± 32.33a
F	1.00	13.60	55.29	194.83	113.15
df	2, 4	2, 4	2, 4	2, 4	2, 4
P	0.444	0.016	0.001	<0.001	<0.001

Within a column numbers followed by different lower-case letters are not significantly different (Tukey test, $P < 0.05$)

Treatments: *F. occidentalis* (Fo) only, *F. occidentalis* + *O. majusculus* (Fo Om), *F. occidentalis* + *O. majusculus* + *Artemia* sp. (Fo Om Art) and *F. occidentalis* + *O. majusculus* + *Artemia* sp. + pollen (Fo Om Art Pol)

Table 3 Mean (±SE) total number of fruits, total weight and fruits with silver spots that were found in each treatment

Treatment	Total number	Total weight (g)	Number of fruits with cosmetic damage
Fo	28.3 ± 3.76a	11.2 ± 1.70a	13.3 ± 4.63a
Fo Om	28.7 ± 1.20a	10.6 ± 0.12a	3.0 ± 1.53a
Fo Om Art	27.7 ± 4.33a	10.1 ± 1.70a	4.7 ± 1.20a
Fo Om Art Pol	24.0 ± 0.58a	8.4 ± 0.12a	1.7 ± 0.88a

Within a column numbers followed by the same lower-case letter are not significantly different (Tukey test, $P < 0.05$)

Treatments: *F. occidentalis* (Fo) only, *F. occidentalis* + *O. majusculus* (Fo Om), *F. occidentalis* + *O. majusculus* + *Artemia* sp. (Fo Om Art) and *F. occidentalis* + *O. majusculus* + *Artemia* sp. + pollen (Fo Om Art Pol)

phloem, do not inflict profound damage in plant tissues since they use their stylet to access the vascular tissue and extract phloem sap (Walling 2000). Thrips, however, damage the epidermal and parenchymatous tissues of the plant and inject saliva, while emptying the cell contents (Kindt et al. 2003), producing more mechanical damage. According to Rodriguez-Saona et al. (2002, 2003) a high level of mechanical damage increases the amount of plant volatiles released, while the attack by sucking insects produces less damage and, as a consequence, the amount of released volatiles by the plant is lower. Plants use these volatiles as a defense mechanism to attract natural enemies (Dicke 1999; Greany and Hagen 1981; Letourneau 1988; Tumlinson et al. 1993; Turlings et al. 1990; Vet and Dicke 1992). Different species of *Orius* have already been demonstrated to have a marked preference for the volatiles of plants attacked by herbivores, such as thrips and spider mites (Karimy et al. 2006; Tatemoto and Shimoda 2008; Venzon et al. 1999). Furthermore, *M. pygmaeus* has been described as being attracted to volatiles released by plants infested with whiteflies, lepidopteran leafminers, red spider mites and aphids (Ingegno et al. 2011; Lins et al. 2014; Moayeri et al. 2006, 2007).

In the semi-field test, *O. majusculus* successfully established in the cages where it was released and effectively controlled the *F. occidentalis* populations, whereas other *Orius* species, like *O. laevigatus* and *O. strigicollis* (Poppius), could not be established in cucumber crops, and therefore, could not control the thrips populations (Chambers et al. 1993; Kim et al. 2004; Rajabpor et al. 2011). In our experiment, prey populations decreased faster when only *Artemia* cysts were provided and this was evident as soon as 1 week after predator release. However, when *Artemia* cysts and pollen were supplemented together, reduction of the thrips population was not recorded until 2 weeks after predator release. This lag in the pest reduction may be due to the fact that pollen but not *Artemia* cysts promote *F. occidentalis* build up (Hulshof et al. 2003; Leman and Messelink 2015; Vangansbeke et al. 2015). In greenhouse experiments, van Rijn et al. (2002) and Leman and Messelink (2015) showed that although *F. occidentalis* feeds on pollen, the greater increase in predator population improves predator–prey ratio and benefits biological control. We did not observe this positive effect of pollen in our greenhouse experiment and this may be due to differences among predators used in the studies (predatory mites vs. anthocorid bugs).

Fruit quality is an important aspect to consider when pest control methods are evaluated, especially in greenhouse crops, due to the high capital investment and production costs involved. Fruits of Dutch-type cucumbers are especially sensitive to thrips, and therefore, the economic threshold for *F. occidentalis* is based on the cosmetic damage that this pest inflicts on the fruits (Rosenheim et al. 1990; Shipp et al. 2000; Welter et al. 1990). Although in our experiment, no statistical differences between different treatments were observed, the number of fruits with cosmetic damage was lower in cages where *O. majusculus* was released than in those without predators.

In summary, our results showed that predatory bugs disperse to the infested plants despite the provision of supplemental food on the release patch. Thus, the addition of supplemental food would not interfere with predator establishment in the infested crop and would provide nutritional resources to predators when the crop is not infested. In addition, the results presented in this paper indicate that the release of *O. majusculus* was very effective for controlling thrips in a greenhouse cucumber crop. The addition of supplemental food only once when predators were released improved their establishment, and the addition of *Artemia* cysts resulted in faster thrips control than the addition of *Artemia* cysts and pollen. However, since we conducted a short-term experiment in semi-field conditions, further verification under commercial conditions would be necessary before the strategy of releasing *O. majusculus* together with the addition of only *Artemia* can be recommended.

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