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Theory and Application in Pest Management

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Ornamental pepper as banker plants for establishment of *Amblyseius swirskii* (Acari: Phytoseiidae) for biological control of multiple pests in greenhouse vegetable production

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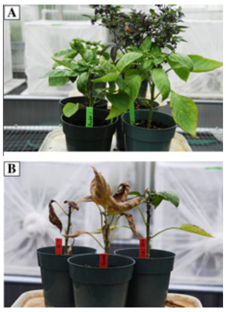
HIGHLIGHTS

- ▶ The ornamental pepper banker system for managing multiple pests was established.
- ▶ Three varieties of ornamental pepper proved to be excellent banker plants.
- ▶ They sustained an effective predator, *Amblyseius swirskii* at the high densities.
- ▶ This system should provide a new approach to control multiple pests in greenhouse.

GRAPHICAL ABSTRACT

(A) Healthy the sweet pepper plants in treatment groups protected by *Amblyseius swirskii* reared on one ornamental banker pepper plant at ~20 d post release; (B) Damaged the sweet pepper plant showing leaf damage symptom in control group.



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ABSTRACT

Silverleaf whitefly, *Bemisia tabaci* biotype B (Gennadius) (Hemiptera: Aleyrodidae), western flower thrips, *Frankliniella occidentalis* (Pergande), and chilli thrips, *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae), are key pests of vegetable crops in the US. The present study established ornamental peppers as banker plants supporting *Amblyseius swirskii* (Acari: Phytoseiidae) against the three pests. Specifically, this study (a) evaluated survival and population buildup of *A. swirskii* on three ornamental pepper varieties, Masquerade (MA), Red Missile (RM), and Explosive Ember (EE) in both laboratory and greenhouses and (b) determined the predation of *A. swirskii* reared on ornamental pepper plants to the targeted pests under greenhouse conditions. The results showed that the three pepper varieties were excellent banker plants and able to support at least ~1000 of all stages of *A. swirskii* per plant in greenhouse conditions and allow them to complete their life cycle. *A. swirskii* dispersed or released from the banker plants to target plants, resulting in significant suppression of the three pests, i.e., after 14 d post-release, a significantly lower average of 2.75 *B. tabaci* and 13.4 all stages of thrips (chilli thrips and western flower thrips) were found per bean plant, respectively, compared to 379.5 *B. tabaci* and 235.4 all stages of thrips per plant in the control. Furthermore, our experiment observed that the sweet pepper seedlings closed to banker plants were healthy, whereas those without banker plants were heavily infested by chilli thrips; their growth seriously stunted or died. This is the first report of ornamental pepper as banker plants supporting *A.*

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swirskii against three notorious pests. This established banker plant system could be a new addition to the integrated pest management programs for sustainable control of these three pests in greenhouse vegetables.

1. Introduction

Consumption of fresh vegetables in the US has steadily increased over the last 20 years. However, some important vegetables such as tomato (*Solanum lycopersicum* L.), sweet pepper (*Capsicum annuum* L.) and green bean (*Phaseolus vulgaris* L.) have faced increasing threats by several serious pests, including silverleaf whiteflies (B and Q biotypes), *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), and chilli thrips, *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae). Silverleaf whiteflies are direct feeders and plant virus vectors (Perring et al., 1993), and has a high propensity to develop resistance to insecticides (Horowitz et al., 2004; Nauen and Denholm, 2005). Both western flower thrips and chilli thrips feed on foliage, resulting in distorted, puckered and twisted leaves, or plant death (Seal and Klassen, 2005). It has been estimated that chilli thrips alone could cause $3–6 billion in crop yield loss annually in the US (Garrett, 2004).

Chemical pesticide application has been the primary method for controlling these pests. With their propensity for developing resistant or tolerant strains and also the increased awareness of sustainable agriculture, biological control has been considered a valuable alternative to the chemical control (Osborne et al., 2005). The predatory mite, *Amblyseius swirskii* (Anthias-Henriot) (Acari: Phytoseiidae), has been widely used against many species of small arthropods (Swirskii et al., 1967; Romeih et al., 2004; Lee and Gillespie, 2011), including thrips (Nomikou et al., 2001, 2003; Messelink et al., 2006, 2008; Arthurs et al., 2009), *B. tabaci* (Nomikou et al., 2002, 2010; Hoogerbrugge et al., 2005), *Tetranychus urticae* (Acari Tetranycidae) (Xu and Enkegaard, 2010; Xiao et al., in press), and other pests on vegetable crops (Messelink et al., 2006). *A. swirskii* has been demonstrated to be a promising agent for biological control of multiple pests. However, a key issue for the effective biological control is to have predator populations established in a timely fashion to suppress targeted pests; otherwise, chemical pesticides have to be applied to suppress the pest populations below the economic injury levels.

Banker plant systems are a relatively new biological control approach (Osborne et al., 2005; Frank, 2010; Huang et al., 2011; Xiao et al., 2011a,b). It consists of a plant that directly or indirectly provides resources, such as food or prey, for natural enemies that are deliberately released within a cropping system. The banker plant system uniquely combines the advantages of both augmentative and conservation biological controls, providing a preventative, long-term suppression of arthropod pests. Therefore, the development of the banker plant system for managing multiple pests has increasingly become an alternative option (Frank, 2010; Xiao et al., 2011a,b).

The overall goal of this study was to develop ornamental pepper banker plants of *A. swirskii* for control of multiple pests in greenhouse productions. The specific objectives were to (a) evaluate survival and population buildup of *A. swirskii* on tested ornamental pepper varieties in both laboratory and greenhouse and, (b) determine the predation by *A. swirskii* to multiple pests after dispersion to targeted crops from ornamental pepper banker plants under greenhouse conditions.

2. Materials and methods

2.1. Host plants and insect pests

Host plants: The seeds of ornamental pepper varieties, Masquerade (MA), Red Missile (RM), Explosive Ember (EE), tomato 'Patio' (Ball Horticultural Co., West Chicago, IL, USA), green bean 'Dusky Bean'(Syngenta Seeds, Inc., Gilroy, CA, USA), and sweet pepper 'California Wonder' (Dave's Garden Co., CA. USA) were sown on cell trays containing Fafard 2-Mix growing medium (Conrad Fafard, Inc., Agawam, MA, USA). Seedlings were transplanted into 8-cm plastic pots filled with the same growing medium and enclosed in insect roof screen cages in air-conditioned rearing rooms and greenhouses [27 ± 2 °C, 60 ± 10% RH, and a photoperiod of 16:8 (L: D) h] at the University of Florida's Mid-Florida Research and Education Center in Apopka, FL, USA. The seedlings (20 d after planting) free of pesticides were used for the experiments described below.

The colonies of the three pests, silverleaf whitefly, western flower thrips and chilli thrips, originally collected from multiple locations, were maintained in air-conditioned greenhouses or rearing rooms. These pests were reared on fully expanded leaves of green bean plants (Dusky Bean, ~30 d old), respectively, and enclosed in screen net cages. Arthropods and plants in different greenhouses were monitored daily.

2.2. Laboratory rearing of predatory mites

The colonies of *A. swirskii* were purchased from Koppert Biological Systems (Koppert Inc., Howell, MI, USA) and reared with mixed pollen (peach and cattail) on a plastic arena in a plastic tray isolated by water. Cotton threads were placed on the plastic tray as shelter for oviposition. The colonies were maintained for several generations before use in the bioassays. All rearing was conducted under laboratory conditions as mentioned above.

2.3. Laboratory test

The development and reproduction of *A. swirskii* on ornamental peppers was investigated using the following protocol. A gravid adult female was confined on a 2.5-cm diameter leaf disc with domatia of each treatment plant until death. Each leaf disc was placed on a moistened filter paper fitted inside a small Petri dish (3.0 cm diameter × 0.5 cm depth). Four small Petri dishes equidistant from each other were fixed in a large Petri dish (15 cm diameter × 1.5 cm) filled with water in order to isolate each smaller dish. The large Petri dishes were then sealed with Parafilm to prevent mites from escaping and the leaf disc desiccating. The experiment had six treatments (varieties or species): three ornamental pepper varieties, one variety of tomato, one variety of green bean, and one filter paper (control). Each treatment (variety) had four large Petri dishes, each large Petri dish contained 4 small Petri dishes with the same type of leaf disc (16 replicates/treatment). A total of 24 large Petri dishes were arranged in a randomized complete block design for each experiment. The numbers of eggs laid, immature developmental time, and gravid female longevity were recorded for each experiment.

2.4. Greenhouse test

In the test, the population abundances of *A. swirskii* on the seedlings of the three ornamental pepper varieties, one variety of tomato and one variety of green bean without any prey were surveyed weekly in a greenhouse for a complete growth period (∼90 d). For each variety, one potted seedling (20 d old at ∼5–7 leaf stages) of each variety was placed in a nylon screened cage (80 × 80 × 80 cm) on March 3 on an inverted small saucer (10 cm dia.) that was placed in a larger saucer (20 cm dia.) filled with soapy water to prevent the predatory mites escaping from the seedling. Five gravid female adults of *A. swirskii* were introduced onto each seedling by camel hair brush. Fourteen days after release of *A. swirskii*, a total of 15 leaves (5 leaves per plant × 3 plants) on each variety were sampled weekly starting on March 18 until the fruit matured. The number of predatory mites (eggs, immature and adults) was counted under a stereoscope. The experiment had five treatments (varieties or species) with three replicates (plants). A total of 15 potted plants were used in the first part of the experiment. However, because there was a 100% mortality of the predatory mites on both the tomato and green bean in the first and the second samplings (2 weeks) post-release of *A. swirskii*, no further survey was performed on these two plant species in the second part.

For the second part of the experiment, only the three varieties of ornamental peppers were assessed. A total of 9 potted plants (3 varieties × 3 replicate plants) were grown and subjected to the same treatments as described above. For the first survey, during the emerging peak of the predatory mite, the number of *A. swirskii* on all leaves, flowers and twigs per potted plant per variety were counted and separated into upper-level (>35 cm high from pot bottom) and mid-level (20–34 cm from bottom) by destructive sampling. For the second survey, after the first destructive samplings, the ornamental plants grew new twigs and leaves. The five gravid females of *A. swirskii* were released on these new flushes, during the second peaking of predatory mite (∼70 d after first sampling), the second destructive samplings were counted using the same methods. The second destructive sampling was conducted to count the number of *A. swirskii* on all leaves, flowers and twigs of the potted plant per variety.

2.5. Percent predation by A. swirskii

Three separate experiments were conducted to determine the percent predation by *A. swirskii* reared on ornamental pepper banker peppers against *B. tabaci*, chilli thrips or thrips complex (80% western flower thrips and 20% chili thrips) infesting targeted crops. The first was to test the suppression of the thrips complex. Uniform and pest-free potted green bean plants ($n = 10$), 20 d after germination with three fully expanded leaves, were selected, and divided into two groups: five plants were used as treatment groups and the other five were used as control. The spatial arrangement consisted of 10 green bean plants placed randomly on two benches in a greenhouse. Each plant was placed on an inverted small saucer that was isolated by soapy water in a large saucer. Two days later, about 15 adult thrips complex were carefully introduced to each plant using a camel hair brush. Seven days later, 5 gravid adult females of *A. swirskii* reared on ornamental pepper plants were introduced onto each plant through the same method as described above in the treatment group. The remaining 5 potted control plants without the release of predatory mites served as control. Each plant was an experimental unit, and there were five replicates. Two weeks post release of the predatory mites, the number of thrips and *A. swirskii* was counted by collecting all leaves of each green bean plant and checked using a head optical glass binocular magnifier magnifier (10×) (Donegan Optical Company, Lenexa, KS, USA).

The second experiment was performed to determine the percent predation of *A. swirskii* against *B. tabaci* in screened cages (80 × 80 × 80 cm). Ten potted ($n = 10$) green bean plants (20 d seedlings) were selected and each placed in a cage. Twenty whitefly adults were introduced into each cage for oviposition. The spatial arrangement was the same as the first experiment in an air-conditioned greenhouse. Two days post whitefly release, five gravid adult females of *A. swirskii* reared on ornamental banker peppers were released onto each bean plant in 5 separate cages in treatment groups for 14 d. The remaining five cages (control) received no release of *A. swirskii*. The experiment was replicated five times. The detection, record and assessment of leaf damage, the number of pests and natural enemies were recorded as described above in experiment one.

The third experiment evaluated the suppression of chilli thrips by *A. swirskii* on the sweet pepper seedlings under greenhouse conditions. Uniform and pest-free potted ($n = 24$) pepper seedlings (30 d old) with 4–5 fully expanded leaves were selected and divided into two groups: 12 potted plants were used as treatment and the other 12 as control. For the treatment group, one pot of banker plant (EE) supporting the predatory mites was immediately placed next to three potted sweet pepper seedlings in an isolated tray. In the arrangement, the predatory mite could easily disperse from the banker plants to the sweet pepper plants in order to feed on chilli thrips. The control treatment was 3 sweet pepper seedlings only in an isolated tray. Each tray was considered as an experimental unit and isolated by same methods as mentioned above. All experimental units were placed randomly on two benches in a greenhouse. The experiment had four replications. Two days later, ∼300 chilli thrips nymphs were introduced to each sweet pepper plant. Three weeks post the release of chilli thrips, the leaf damages of the sweet pepper seedlings were photographed. The number of pest insects and predatory mites were not counted.

2.6. Data analysis

The data (eggs number, motiles and total number of the predatory mites) obtained from laboratory and greenhouse experiments were first normalized by using the square-root ($\sqrt{x} + 0.5$) if necessary. Significant differences for each experiment were established using either one-way analysis of variance (ANOVA), followed by Tukey–Kramer honestly significant difference (HSD) comparison test or student's t test ($P < 0.05$, JMP Version 8.01, SAS Institute, 2009).

3. Results

3.1. Development of A. swirskii

Laboratory test showed that *A. swirskii* was able to develop and oviposit on the three varieties of ornamental peppers. The number of eggs on leaf discs of ornamental pepper plants was significantly greater than that on leaf discs of the tomato and green bean plants (Table 1). Female adult longevity of *A. swirskii* was ∼14–26 d on ornamental pepper plants compared to 7–11 d on leaf discs of tomato and green bean plants.

3.2. Population buildup of A. swirskii

A. swirskii developed overlapping generations and sustained high population densities on the three ornamental pepper varieties (MA, RM, and EE). Eggs, immature, and adults were gregarious in domatia of these varieties (Fig. 1). Seasonal weekly surveys showed

Table 1
Survival, development and reproduction of *A. swirskii* on the leaf discs of three ornamental pepper, tomato, and green bean plants in the laboratory test.

Host plants[a]	Mean (±SE) number		
	No. Eggs	Immature[b] development (days)	Female adult longevity[c] (days)
MA	1.87 ± 0.2 A	11.6 ± 0.9 A	14.0–26.0
RM	2.37 ± 0.1 A	10.3 ± 2.1 A	14.0–17.0
EE	1.87 ± 0.1 A	10.9 ± 1.3 A	14.0–17.0
Tomato	0.62 ± 0.1 B	–	8.0–10.0
Green bean	0.51 ± 0.1 BC	–	7.0–11.0
Filter paper (CK)	0.25 ± 0.2 C	–	5.0–8.0

[a] MA (Masquerade); RM (Red Missile); EE (Explosive Ember); Experiment was replicated 16 times.
[b] No developmental time in tomato and green bean plants was observed, since *A. swirskii* died during the periods.
[c] Initial gravid female adults obtained from rearing colony. Mean numbers in a column with same letters are not significantly different (Tukey's HSD, $P < 0.05$).

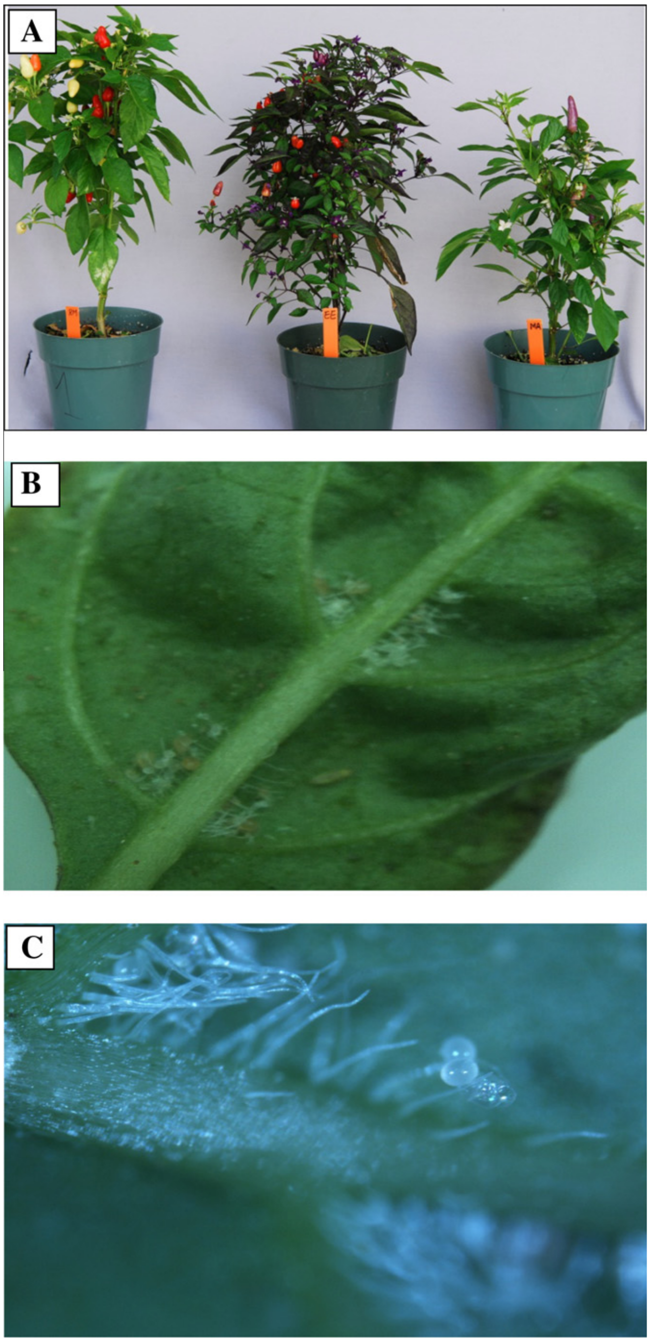

Fig. 1. Three varieties of ornamental pepper (MA = Masquerade, EE = Explosive Ember, and RM = Red Missile) provided food nutrient resource for *A. swirskii*. (A) The seedlings of the three varieties of ornamental peppers at the blooming and fruit periods; (B) the motiles of *A. swirskii* on leaf surface of ornamental pepper and (C) eggs associated with tuft domatia on leaf surface.

that there was a high population buildup on all the ornamental pepper varieties (Fig. 2). The densities of *A. swirskii* increased rapidly on the seedlings at ~30 d (early April), reached peaks at ~45 d (mid April), gradually decreased at ~75 d (mid of May), and then maintained low-moderate levels at ~90 d after release (late May and June) or until first pepper fruit matured. The peak mean number of *A. swirskii* all stages was ~11.7–25.1 per leaf during the 3rd–5th sampling period. Nevertheless, *A. swirskii* were sustained throughout the sampling period from young seedlings to mature plants with fruit, with the highest densities occurring during blooming periods. Because these ornamental pepper varieties have multiple blooming periods, continuous overlapping generations and peaks were observed.

Among the three varieties of ornamental peppers, EE held the significantly highest numbers of eggs (~600) and motiles (~600), and total number (~1000–1200) per potted plant (Table 2), for example, EE held a significantly higher number of *A. swirskii* than RM and MA at the first survey (eggs: $F = 25.44$; $df = 2, 6$; $P = 0.001$; motile: $F = 11.3$; $df = 2, 6$; $P = 0.0106$; total number: $F = 14.91$; $df = 2, 6$; $P = 0.004$) and at the second survey (eggs: $F = 21.42$; $df = 2, 6$; $P = 0.0018$; motile: $F = 8.3$; $df = 2, 6$; $P = 0.018$; total number: $F = 10.9$; $df = 2, 6$; $P = 0.01$). In addition, *A. swirskii* was observed to prefer to stay in top canopy in which the plant held more flowers and pollens (Table 3). In contrast, *A. swirskii* was observed to not have survived on tomato and green bean plants ~15 d after release.

3.3. Predation by A. swirskii

A. swirskii heavily preyed on *B. tabaci* and thrips in the greenhouse experiments (Figs. 3 and 4). The first experiment (against thrips complex) indicated that *A. swirskii*, reared on ornamental pepper plants, showed significant suppression of the population of the thrips complex (excluding eggs, because of the difficulty in counting eggs in the greenhouse by magnifier) infesting the green bean plants ($t = 7.87$; $df = 8$; $P = 0.001$). The number of thrips complex in the treatments was only 13.4 per plant (based on total leaves) compared to 235.4 per plants in the control.

The second cage experiments (against *B. tabaci*) showed that *A. swirskii* reared on ornamental pepper plants significantly regulated the population of *B. tabaci* infesting the green bean plants ($t = 4.05$; $df = 8$; $P = 0.0067$). The mean number of *B. tabaci* motile stages (excluding eggs) was 2.75 per plant (based on all leaves) in the treatments compared to 379 per plant in the control (Fig. 3). Also, *A. swirskii* produced 6.25–53.4 motiles (excluding eggs) per plant in the treatments.

The third experiment (against chilli thrips) further confirmed that ornamental pepper banker plants holding *A. swirskii* populations effectively suppressed heavy populations of chilli thrips infesting the sweet pepper plants through dispersion of *A. swirskii*. In the control group, the sweet pepper plants was seriously

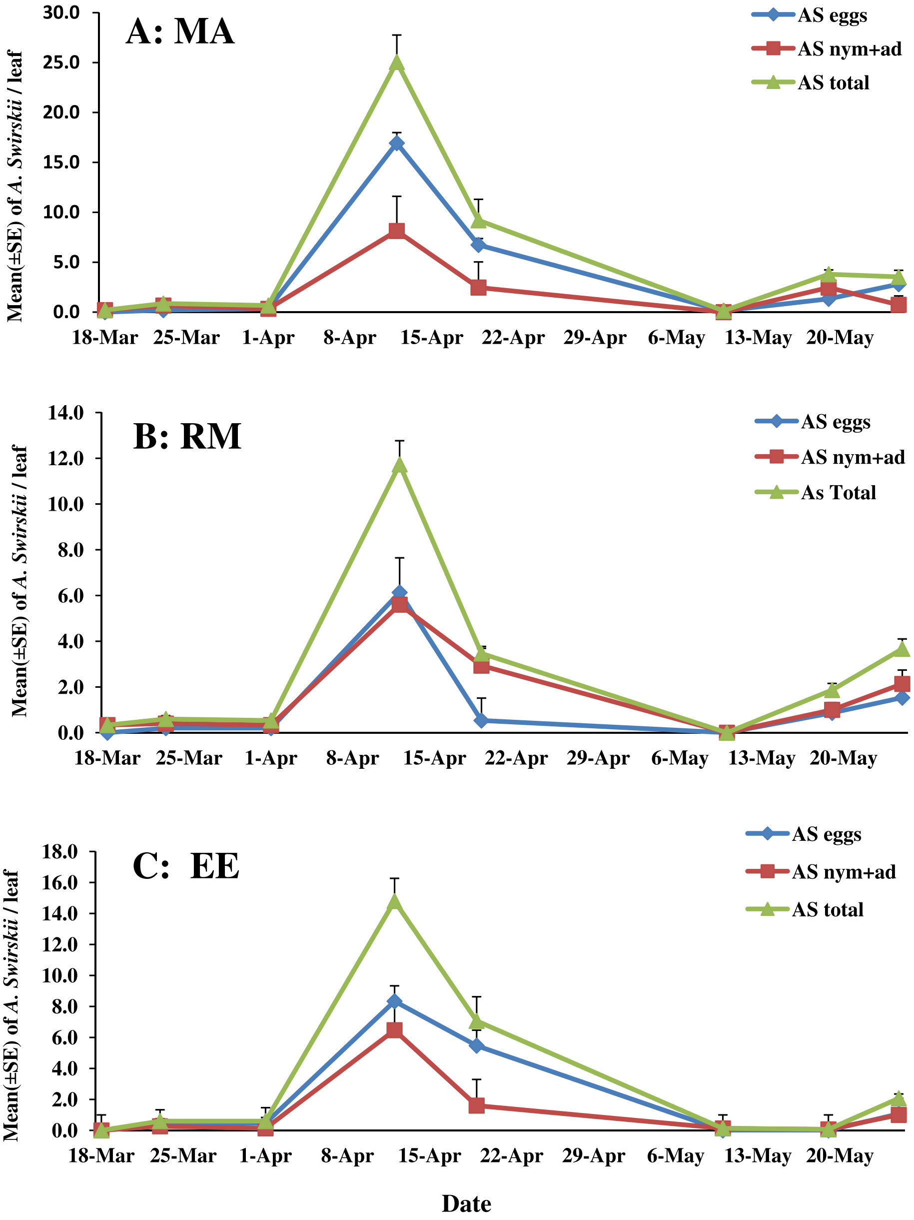

Fig. 2. The mean number of *A. swirskii* (As) (eggs, nym + ad or total (all stages) per leaf on each of the three ornamental pepper varieties in greenhouse experiment (A: MA = Masquerade), (B: RM = Red Missile), and (C: EE = Explosive Ember).

Table 2
The number of all stages of *A. swirskii* on each of the three varieties of ornamental peppers in a growth period in the greenhouse.

Survey times	Host plants[a]	Mean (±SE) numbers per plant (all leaves)			
		No. leaves	No. eggs	No. motiles[b]	No. total[c]
1st	EE	244 ± 19	512 ± 31 A	445 ± 41 A	957 ± 72 A
	MA	119 ± 35	319 ± 23 B	195 ± 34 B	514 ± 56 B
	RM	189 ± 20	61 ± 15 B	260 ± 25 B	320 ± 41 B
2nd	EE	200 ± 11	592 ± 29 A	605 ± 54 A	1197 ± 82 A
	MA	110 ± 21	229 ± 25 B	294 ± 44 B	523 ± 56 B
	RM	168 ± 15	133 ± 25 B	316 ± 29 B	449 ± 41 B

[a] MA (Masquerade); RM (Red Missile); EE (Explosive Ember). Mean numbers in a column with the different letters are significantly different (Tukey's HSD $P < 0.05$).

[b] Motiles = immatures + adults.

[c] Total = eggs + motiles.

Table 3
The mean number of all stages of *A. swirskii* on the upper- and mid-level canopy of the three ornamental pepper varieties in the greenhouse.

Host plant[a]	Leaf location[b]	Mean (±SE)/leaf[c]	t Value	*df*	*P*
RM	Upper-level	1.97 ± 0.18 A	3.328	186	0.001
	Mid-level	0.87 ± 0.35 B			
MA	Upper-level	5.07 ± 0.69 A	1.581	117	0.1
	Mid-Level	3.28 ± 0.81 A			
EE	Upper-level	3.76 ± 0.42 A	0.189	241	0.8499
	Mid-Level	4.11 ± 0.55 A			

[a] MA (Masquerade); RM (Red Missile); EE (Explosive Ember).

[b] Upper level (>35 cm high), mid-level (20–34 cm up from pot bottom) a few predatory mite were found below the 20 cm height, so they are not counted.

[c] Mean numbers in a column with same letters are not significantly different (Tukey's HSD $P < 0.05$).

"burned" or died due to being heavily fed upon by the chilli thrips (Fig. 4).

4. Discussion

4.1. Biology and population buildup of A. swirskii

The biology and ecology of *A. swirskii* in the presence of prey have been studied by several researchers (El-Laithy and Fouly, 1992; Park et al., 2010; Lee and Gillespie, 2011). However, there is little information regarding the biology of *A. swirskii* on plant hosts in the absence of prey. The present study documented that *A. swirskii* was able to complete its life cycle, and build up its population on flowering ornamental pepper plants without any prey (Tables 1 and 2 and Fig. 2). These results were consistent with those of Lee and Gillespie (2011), which indicated that *A. swiskii* populations would reproduce quickly in response to food availability (pollen or prey) under favorable conditions. In addition, we noted that the developmental time of *A. swirskii* immatures on the ornamental pepper plants (10.0 d) was longer than on the other food resource, such as cattail pollen (6.2 d) at 25 °C (Park et al., 2010), on *F. occidentalis* (Thysanoptera: Thripidae) (7.8 d) at 25 °C (Wimmer et al., 2008), and on *T. uriticae* (3.84 d) at 26 °C (El-Laithy and Fouly, 1992). The variable developmental time could be related to food type and leaf surface structure of three varieties of ornamental peppers. However, whether *A. swirskii* can complete its life cycle on the sweet pepper plants has not evaluated yet in the experiments.

Among the three varieties tested in the greenhouse, variety EE held the highest number (~1200) of all stages of *A. swiskii* per plant. This can be attributed to the facts that EE had more leaves (200–244) than variety MA (110–119) or RM (158–189). If the individuals were allowed to quickly disperse, the predatory mites could significantly suppress the pest population (Figs. 3 and 4). As indicated by Frank (2010), non-crop host plants are particularly favored for use as banker plant, because they serve as an alternative food or shelter for a parasitoid or predator. The three varieties of ornamental pepper plants proved to be excellent banker plant hosts for supporting *A. swirskii* populations without any prey (Tables 1 and 2). The three varieties held the maximum number of *A. swirskii* at the blooming periods (Fig. 2), suggesting that the ornamental pepper pollens could be the one of most preferred food sources of *A. swirskii*.

Some researchers have documented that the domatia positively enhanced predator numbers in the different ways: (a) as a shelter for breeding and development, (b) increasing the fungal spores which might serve as alternative food sources, (c) moderating the micro-environment, especially humidity, and (d) affording protection from intraguild predation (Roda et al., 2000; Romero and Benson, 2005; Loughner et al. (2008). Therefore, a preference of the three ornamental pepper varieties as host plants by *A. swirskii* may be related to the presence of tuft domatia. A detail study and discussion of the predatory mite related to the domatia of ornamental pepper plants had been summarized in another manuscript which is being reviewed. Whether the presence of the possible specific stimuli chemical is not detail studied yet.

Temperature is an important factor influencing predator establishment. Lee and Gillespie (2011) suggested that the desired average daily temperature for *A. swirskii* through the year is 25–32 °C. Our results demonstrated that *A. swirskii* successfully established populations on the three varieties of ornamental pepper under the greenhouse conditions in Florida (27 ± 2 °C) (Table 2), Suggesting most greenhouse conditions in Florida are suitable for the predatory mite population buildup.

4.2. Predation by A. swirskii

The predatory mite, *A. swirskii*, feed on many species of small arthropods in the vegetable crops (Swirskii et al., 1967; Nomikou

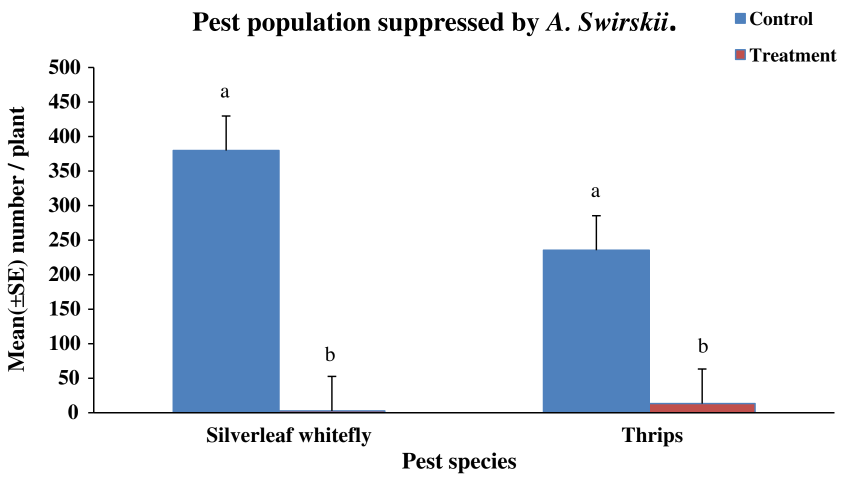

Fig. 3. The mean numbers of silverleaf whitefly and thrips complex (mixed western flower thrips and chilli thrips) per plant were significantly suppressed by *A. swirskii* that established on ornamental pepper banker plants in both the treatment than that of the control without release. For same pest, the mean number (±SE) of the pest per plant with different letters is significantly different ($P < 0.05$).

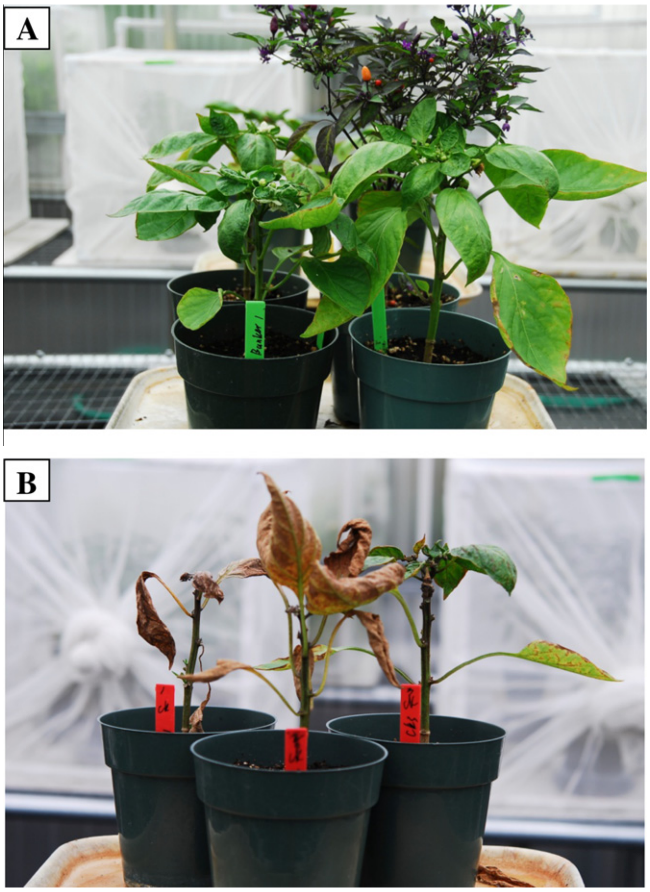

Fig. 4. Healthy the sweet pepper plants in treatment group (A) protected by *A. swirskii* (all stages) holding on one ornamental banker pepper plant at ~20 d post release; Damaged the sweet pepper plant showing leaf damage "burn" in control group (B).

et al., 2010; Messelink et al., 2008; Lee and Gillespie, 2011; Xiao et al., in press). In particular, it is a dominant predator of thrips and a highly effective predator of *B. tabaci* eggs and young instars. Therefore, the predation of a biocontrol agent from banker plants has become one of the most critical factors for determining the success of a banker plant system. The present studies confirmed that *A. swirskii* reared on the three varieties of ornamental pepper effectively predated on both *B. tabaci* and chilli thrips or thrips complex (Figs. 3 and 4). To our knowledge, this is the first documentation of ornamental peppers as banker plants supporting *A. swirskii* against three key pests.

4.3. Ornamental pepper as banker plants for A. swirskii

Ornamental pepper varieties provide sufficient food resources for *A. swirskii*, which has no detrimental effects on tomato, green bean and pepper crops. The established banker plant system was affordable because a large number of *A. swirskii* could be easily reared on ornamental pepper plants with only one time purchase. The additional food resources for supporting predator reproduction has been demonstrated to successfully regulate multiple pests, such as silverleaf whitefly, chilli thrips, and western flower thrips in the targeted crops (Rijn et al., 2002; Goolsby and Ciomperlik, 1999; Pickett et al., 2004; Van Driesche and Heinz, 2004). Additionally, ornamental pepper banker plants provide commercial growers with great flexibility in introducing *A. swirskii* prior to a targeted pest occurrence without the risks; however, augmentative biological control agent must be released at a critical time and used in the designated methods (Collier and Van Steenwyk, 2004; Crowder, 2007). In addition, the ornamental pepper plants are easily grown and managed under greenhouse temperature in Florida with a range of 25–30 °C, which is the most favored for *A. swirskii* reproduction. Furthermore, this ornamental pepper banker plant system could be compatible with other chemical control, because the banker plants would be easily moved out of the greenhouses when chemical pesticides have to be applied to the target crops. It is anticipated that this established banker plant system could be an additional tool for sustainable control of the three pests in greenhouse vegetable production.

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