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Influence of banker plants and spiders on biological control by *Orius insidiosus* (Heteroptera: Anthocoridae)

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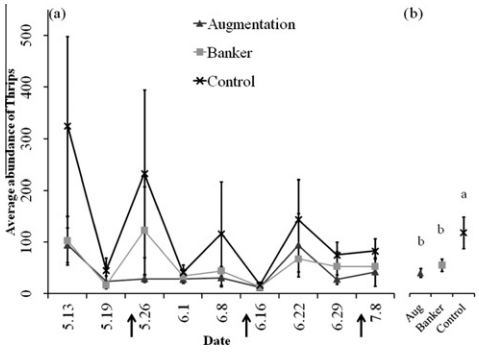
HIGHLIGHTS

- Banker plants did not improve biological control by *Orius insidiosus*.
- Pollen, as alternative food, did not reduce predation by *O. insidiosus*.
- Spider colonized banker plants reducing *O. insidiosus* access to pollen.
- Banker plants appear best suited for indoor greenhouse crops.

GRAPHICAL ABSTRACT



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ABSTRACT

Banker plant systems are a form of conservation biological control intended to enhance natural enemy efficacy by providing an alternative source of food when prey items are scarce or absent. The Black Pearl pepper, *Capsicum annuum* 'Black Pearl', banker plant system provides pollen to sustain populations of the omnivorous predator *Orius insidiosus* say (Heteroptera: Anthocoridae). Black Pearl pepper pollen has been shown in previous studies to increase *O. insidiosus* longevity, survival to adult, female size, and abundance, and decrease nymphal development time. However, there is no research demonstrating the efficacy of this banker plant system in commercial crop production. We investigated the efficacy of the Black Pearl pepper banker plant system compared to augmentative releases of *O. insidiosus* for thrips management at a commercial nursery that produces native and ornamental grasses. We found that augmentative releases of *O. insidiosus* effectively reduced thrips abundance in hoop houses compared to houses where no predators were released. However, the presence of banker plants did not further reduce thrips abundance. Interestingly, we found spiders in 82% of banker plant samples during this experiment and hypothesized that spiders could reduce access to floral resources provided by banker plants, thus reducing their benefits for biological control. We found that spiders reduced *O. insidiosus* abundance on banker plants by increasing the rate at which *O. insidiosus* emigrate and reducing their survival. We conclude that this banker plant system may be more successful in enclosed growing systems where higher-order predators and emigration of *O. insidiosus* is restricted.

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1. Introduction

Banker plant systems are a form of conservation biological control intended to increase natural enemy longevity and reproduction within a cropping system (Frank, 2010). Banker plant systems consist of non-crop plants that provide alternative hosts for parasitoids, prey for predators, or plant based resources such as nectar and pollen for omnivores (Frank, 2010). For example, a banker plant system

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targeting aphids uses potted grain plants infested with non-pest aphids to provide hosts for parasitoid wasps (Goh et al., 2001; Van Driesche et al., 2008). This allows parasitoids to reproduce in greenhouses even when pest aphids are absent. Interest in banker plant systems is increasing among researchers and growers due to their potential to improve biological control by sustaining natural enemy populations (Frank, 2010; Huang et al., 2011). However, there is uncertainty as to how banker plant systems will perform across a variety of growing systems with different crops and management practices.

Recently, the Black Pearl pepper (*Capsicum annuum* 'Black Pearl') banker plant system has been used by growers to improve biological control of thrips by the minute pirate bug, *O. insidiosus* say (Wong, 2012; Valentin, 2011). Biological control of thrips generally consists of augmentative releases of predatory mites (Acari: Phytoseiidae) or *Orius* spp. (Heteroptera: Anthocoridae) (van Lenteren, 2000; Reitz, 2009). However, thrips suppression has been mixed when using either predator alone or in combination (Shipp and Wang, 2003; Silveira et al., 2004; Messelink et al., 2006; Chow et al., 2010). Unreliable efficacy stems in part from predator mortality or emigration when pollen or prey is unavailable as food within the crop. Pollen from Black Pearl peppers has been shown to decrease *O. insidiosus* nymphal development time, and increase survival to adult, longevity, female size, and overall abundance on flowering peppers (Wong, 2012). Although Black Pearl pepper pollen improves *O. insidiosus* fitness and abundance in laboratory experiments, the efficacy of this banker plant system has never been tested empirically.

Providing plant resources as a conservation biological control tactic, can increase natural enemy abundance and diversity (Lavandero et al., 2005; Gardiner et al., 2009; Atakan, 2010). In some cases this tactic increases pest suppression (Root, 1973; Lavandero et al., 2005; Irvin et al., 2006). In other cases conservation biological control tactics disrupt biological control since providing alternative plant resources may reduce predator consumption of pests (Frank et al., 2011). In addition, increasing predator abundance and/or diversity can result in predation of biological control agents by higher-order predators (Rosenheim et al., 1993; Vance-Chalcraft et al., 2007). In contrast, alternative food can reduce negative interactions biological control agents in some cases (Rosenheim et al., 1995; Frank et al., 2010). Since intraguild predation is common among biological control agents released to control thrips (Chow et al., 2008, 2010), the potential for banker plant systems to increase or decrease negative interactions between predators will be an important factor affecting their efficacy (Frank, 2010).

As nursery and greenhouse growers are already interested in implementing banker plant systems, and Black Pearl pepper pollen has been shown to improve *O. insidiosus* fitness and abundance, the next important step in developing this banker plant system is to implement it in a commercial setting and observe interactions that affect its efficacy. The first objective of this study was to determine how a Black Pearl pepper banker plant system affected pest and natural enemy abundance in a commercial nursery. Secondly, we tested whether the presence of pollen affected *O. insidiosus* predation of thrips. Lastly, we examined how the presence of higher-order predators, endemic spiders, affected retention of *O. insidiosus* released on banker plants. By observing the Black Pearl pepper banker plant system where it is currently being used, and testing hypotheses that might affect its efficacy, we hope to provide useful insight to improve efficacy and adoption of the Black Pearl pepper banker plant system.

2. Methods

2.1. Effect of banker plants on pest abundance

To determine how Black Pearl pepper banker plants affected pest and natural enemy abundance compared to augmentative releases, we conducted an experiment at Hoffman Nursery in Rougemont, NC, which produces native and ornamental grasses in plastic covered hoop houses. Hoffman Nursery was selected for these experiments because they had been implementing the Black Pearl pepper banker plant system for two growing seasons and presently manages several of their hoop houses each season with biological control, using purchased natural enemies and compatible insecticides. The hoop houses used in these experiments were all 6.7 m wide but had different lengths ranging from: smallest (25.6 m) to largest (38.4 m). Sides of the houses were rolled up in summer to maintain a cooler temperature. Each house had four rows of grasses in 30.48 × 60.96 cm flats with 32 grass plugs per flat. Each row was two flats wide (1.22 m) and as long as the houses.

We set up two treatments 'Augmentation' in which *O. insidiosus* were released and 'Banker Plant' in which *O. insidiosus* were released in combination with banker plant installation. In 'Control' houses we did not release *O. insidiosus* or install banker plants. Each treatment was replicated four times in 12 hoop houses. Augmentation and banker plant houses were treated the same as control houses except that we released one bottle of 500 count *O. insidiosus* (Koppert Biologicals, Howell, MI) per house every three weeks (May 25th, June 15th, and July 7th, 2010). *O. insidiosus* were released by sprinkling them evenly on plant flats moving lengthwise from one end of the house to the other. Banker plant houses had Black Pearl pepper banker plants (2–3 feet tall; 9" pot) spaced six per row at alternating lengths within the house (Fig. 1) resulting in 24 banker plants per banker plant treatment house, with the exception of the smallest house which only had five banker plants per row for a total of 20 banker plants. Banker plants were grown in Fafard 2P soil mix (Agawam, MA) with 397 g of Scotts Osmocote (N–P–K: 14–14–14) fertilizer (Marysville, OH) for every 0.08 m^3 of soil. To encourage continuous flowering, we picked peppers from each banker plant in banker plant houses for 1–2 min each week. Houses were not treated with synthetic insecticides but were spot-treated occasionally with insecticidal soap for aphids, spittle bugs, and leafhoppers which are not pests targeted by *O. insidiosus*. All houses were treated weekly with a rotation of fungicides (azoxystrobin, triazzole, iprodione, *Trichoderma harzianum* strain T-22, thiophanate-methyl, myclobutanil, polyoxin, phenylamide, strobilurine, carboxylic acid amide, mancozeb).

Arthropod sampling was conducted once a week for nine weeks (26 May–20 July, 2010) by vacuuming plant flats using a modified Husky Blower Vac (Husqvarna, 125 BVX Series) fitted with organdy (Jo-Anns Fabric, Raleigh, NC; holes 0.02 mm) bags to catch insects. Vacuum sampling is a standard method by which by researchers sample arthropods (e.g. Stewart and Wright, 1995; Hossain et al., 1999; Elliot et al., 2006). A vacuum could be used to sample a specific and repeatable area per house, which was an advantage over sweep nets in our system. In addition, a preliminary trial indicated that vacuuming did not cause damage to the crop whereas sweeping with a net damaged grasses and pulled them from their pots.

One randomly selected 1.22 × 1.83 m section of grasses was vacuumed in each row (four per house) for a total of 8.93 m^2 per house. The four samples from each house were vacuumed into a single organdy bag. Bags were placed in a sealed jar in the freezer for 24 h to kill arthropods. Then the contents of each bag were emptied into a jar of 70% ETOH for later observation. Samples were viewed under a dissecting scope to count *O. insidiosus*, thrips and spider mites. Unfortunately we did not realize the importance of spiders in our system until week 7 so we only counted spiders in our samples on weeks 7, 8, and 9. On weeks when natural enemies were released, sampling took place the day after release. Adult and larval thrips and spider mites captured during the first sample date were identified to species with the help of a diagnostician in the North Carolina State University Plant Disease and Insect Clinic.

Fig. 1. Banker plants at Hoffman Nursery (left, picture by Steven Frank) and banker plant layout schematic displaying four rows of grasses with alternatively spaced banker plants (right).

Pictures and voucher specimens were kept in the laboratory to aid in identification of thrips and spider mites in other samples.

We used a maximum likelihood repeated measures ANOVA to determine how banker plants and augmentative release affected the seasonal abundance of thrips and spider mites. All data were log $(x+1)$ transformed to correct for non-normal distribution (SAS, 2008). We used the NPAR1WAY procedure in SAS to conduct a non-parametric Kruskal–Wallis test to compare the total number of *O. insidiosus* captured in each treatment during the experiment.

2.2. Banker plant sampling

Individual banker plants were sampled to monitor for *O. insidiosus*, spiders, and thrips. Four plants from each banker plant treatment house were sampled every week from June 8th–July 23rd by randomly selecting one plant from each of the four rows in a house and beating the plants over a 33×40.5 cm white tray. Organisms were counted then returned to the plant.

2.3. O. insidiosus predation in the presence and absence of Black Pearl pepper pollen

To determine if the presence of pollen affected *O. insidiosus* predation rate of western flower thrips, we conducted a factorial experiment with two flower treatments (present or absent) crossed with two predator treatments (*O. insidiosus* present or absent). The experiment was conducted in arenas made from plastic 50 mL Corning vials (Corning, NY). One hole (2 cm diameter) was made in the top and side of each vial for ventilation. Holes were covered with thrips screen and secured with hot glue to prevent escape of experimental organisms. A third smaller hole (0.7 cm diameter) was made through the bottom tip of the vial. Each arena had a 6–8 cm Black Pearl pepper stem with three leaves collected from greenhouse pepper plants. All buds and flowers were picked from 'flower absent' treatment stems. Buds and 1–2 open flowers were left on stems in 'flower present' treatments. The bottom-half of each stem was wrapped in cotton then pulled through the small hole in the bottom of vials so that the stem fit snugly in the hole. The cut end was inserted into a #55 (12.7 cm, 10 ml) floral-pick (Syndicate Sales Inc., Kokomo, Indiana) filled with tap water. Floral-picks were stuck into a Styrofoam board and a wire-grid was made from craft wire in order to support the experimental vials in an up-right position. We placed 30 adult thrips in each container and then added a single female *O. insidiosus* to 'predator present' treatment vials. After 48 h all contents of the vials were emptied and thrips were counted as alive or dead.

2.4. Statistical analysis

ANOVA was used to test the effect of pollen, predators, and their interaction on total number of thrips remaining alive (SAS, 2008).

2.5. How spiders affect O. insidiosus retention on banker plants

To determine how spiders affected *O. insidiosus* abundance and retention on Black Pearl pepper banker plants, we manipulated wandering spider abundance on banker plants at Hoffman Nursery. In follow-up experiments we measured the consumptive effects of spiders on *O. insidiosus* abundance and retention by restricting *O. insidiosus* emigration with cages. Then we measured the non-consumptive (behavioral) effects of spiders on *O. insidiosus* by creating 'risk only' spiders that had glued mouthparts and could scare but not consume *O. insidiosus*.

In the first experiment, we tested the abundance and retention rate of *O. insidiosus* on banker plants at Hoffman Nursery by conducting a factorial experiment with two spider treatments (present or absent) crossed with two sampling time treatments (1 or 3 h). Eight banker plants from each banker plant treatment house were prepared by beating them to remove spiders and *O. insidiosus*. Spiders were then collected from the surrounding landscape by beating grasses and banker plants and used within 1 h of collection. Salticidae spiders were used because they were the most prevalent spider family on banker plants at Hoffman Nursery. Twenty *O. insidiosus* (Koppert Biologicals, Howell, MI) were added to banker plants, followed by 4 spiders. After 1 or 3 h, plants were sampled by beating them over a white tray (33×40.5 cm) to count *O. insidiosus* and spiders. This experiment was repeated 30 June and 14 July 2010 for a total of 16 replicates per treatment.

To test the consumptive effects of spiders on *O. insidiosus* abundance and retention rate, we conducted another factorial experiment in a research greenhouse at North Carolina State University on July 21st, 2010. Treatments were the same as in the first experiment at Hoffman Nursery. Plants were individually caged by placing them into 60 cm wide $\times$ 121.9 cm tall organdy bags (Jo-Anns Fabric, Raleigh, NC) so that *O. insidiosus* could not emigrate from plants. Approximately 120 spiders were captured from natural areas on campus, 75% of which were Oxyopidae, the third most prevalent spider family on banker plants at Hoffman Nursery, and 25% were Salticidae. Spiders were held in individual petri dishes in a cooler while we transported them to the greenhouses where we conducted the experiment and used within 4 h of capture. After adding 20 *O. insidiosus* to each plant, 4–6 randomly selected spiders were added to 'spiders present' treatment plants.

Plants were sampled at 1 or 3 h as described above to count *O. insidiosus* and spiders. Banker plants that were similar in size, age, and maintenance to banker plants at Hoffman Nursery were used in this experiment for a total of 10 replicates for each treatment.

To test behavioral effects of spiders on *O. insidiosus* abundance and retention rate on banker plants, we conducted another factorial experiment at North Carolina State University on August 21st, 2010. The treatments and sampling methods were as described above in the previous two experiments. However, plants were not in cages so *O. insidiosus* could emigrate from plants. 'Risk only' spiders with non-functioning mouthparts were used to measure *O. insidiosus* that were emigrating from banker plants instead of being consumed by spiders. To do this, spider mouthparts were glued prior to the experiment with 'Liquid Bandage' (Rite Aid Corporation, Harrisburg, PA) surgical glue that is non-toxic and dries quickly. To apply glue, spiders were rendered unconscious with CO_2 and then held upside down with soft forceps to expose their mouthparts so that a small drop of glue could be applied with a camel-hair paintbrush. Once the glue was dry, spiders were placed in individual petri dishes in a refrigerator and used within 24 h for the experiment.

For each of the above experiments, we conducted control experiments in the lab to determine if the spiders in each experiment were able to capture and consume *O. insidiosus*. The objective of these experiments was to determine if our gluing method prevented predation of *O. insidiosus* so we could document that we had indeed created "risk only" spiders. To do this, we placed individual spiders in each of five petri dishes with five *O. insidiosus* per dish and checked the petri dishes at 1 and 3 h to count eaten or dead *O. insidiosus*. In all of the above experiment we used adult spiders that were identified to family and did not discriminate between genders.

2.6. Statistical analysis

Two-way ANOVA was used to test the effect of spiders, time, and their interaction on number of *O. insidiosus* recovered on banker plants (SAS, 2008).

3. Results

3.1. Effect of banker plants on pest abundance

Nearly all thrips captured were *Frankliniella occidentalis*. Less than 1% of thrips did not fit the morphotype of our *F. occidentalis* vouchers and were not included in the analysis. Overall, there were more than twice as many thrips in the control treatment houses than either the banker plant or augmentation treatment houses ($F = 7.56$; df = 2,107; $P = 0.0008$; Fig. 2). The overall effect of time on thrips abundance was significant ($F = 7.35$; df = 8,107; $P < 0.0001$) but the interaction of treatment and time was not ($F = 0.41$; df = 16,107; $P = 0.9768$).

All spider mites included in the analysis were two-spotted spider mites *Tetranychus urticae* Koch. Spider mites that did not match our voucher specimens (<1%) were not included in the analysis. There were more than six times as many spider mites in the control houses than the augmentation treatment and the overall treatment effect was significant ($F = 7.74$; df = 2, 12.4; $P = 0.0066$; Fig. 3). The overall effect of time ($F = 4.71$; df = 8, 95.6; $P < 0.0001$) on spider mite abundance was significant, but the interaction of treatment and time was not ($F = 0.94$; df = 16, 95.6; $P = 0.5237$). The average number of *O. insidiosus* captured per sample was significantly greater in augmentation houses (0.43 ± 0.2) than control houses (0.03 ± 0.03; $\chi^2 = 4.23$; df = 1; $P = 0.039$) and significantly greater

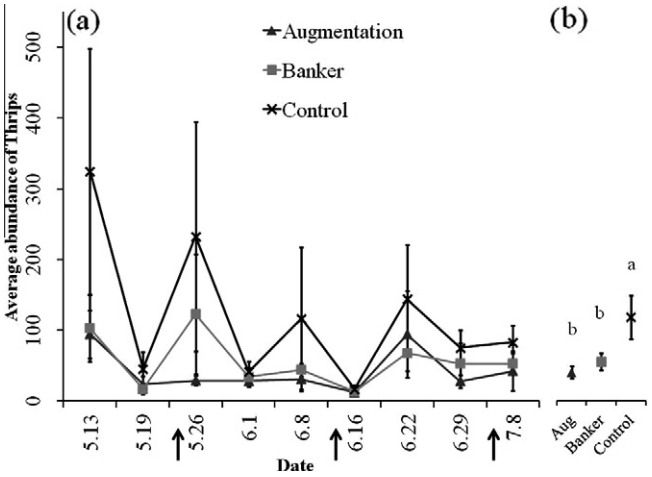

Fig. 2. (a) Weekly mean (±SEM) of thrips abundance over the course of nine weeks. (b) Overall seasons mean of thrips abundance in augmentation (Aug), banker plant (Banker), and control houses. Arrows indicate when *O. insidiosus* releases were made. A significant difference between treatments is indicated by different lower case letters ($P < 0.05$).

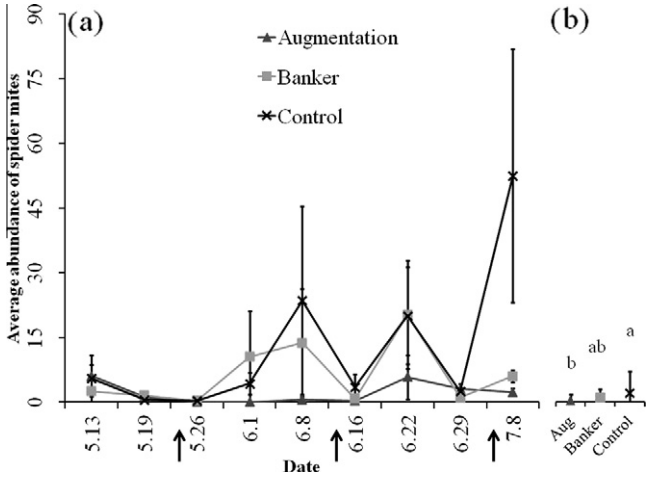

Fig. 3. (a) Weekly mean (±SEM) of spider mite abundance over the course of nine weeks. (b) Overall seasons mean of spider mite abundance in augmentation (Aug), banker plant (Banker), and control treatments. Arrows indicate when *O. insidiosus* releases were made. A significant difference between treatments is indicated by different lower case letters ($P < 0.05$).

in banker plant (0.31 ± 0.1) houses than control houses ($\chi^2 = 7.40$; df = 1; $P = 0.007$) but there was no difference between augmentation and banker plant houses ($\chi^2 = 0.33$; df = 1; $P = 0.567$). There was not a significant difference in the mean number of spiders captured per sample in the augmentation (4.6 ± 1.3), banker plant (7.3 ± 0.1), or control houses (10.3 ± 0.03; $F = 0.90$; df = 2, 24; $P = 0.419$). There was a significant effect of time on the number of spiders captured $F = 6.94$; df = 2, 24; $P = 0.004$) but no interaction between treatment and time ($F = 0.19$; df = 2, 24; $P = 0.941$).

3.2. Banker plant sampling

Spiders were found in 82% of total banker plant samples. The most prevalent spider family on banker plants was Salticidae, followed by Lycosidae and Oxyopidae. *O. insidiosus* adults and nymphs were only found in 8 (7%) banker plant samples over the course of the entire experiment. Other organisms found in banker plant samples but in low abundance were *F. occidentalis* (52%), *T.*

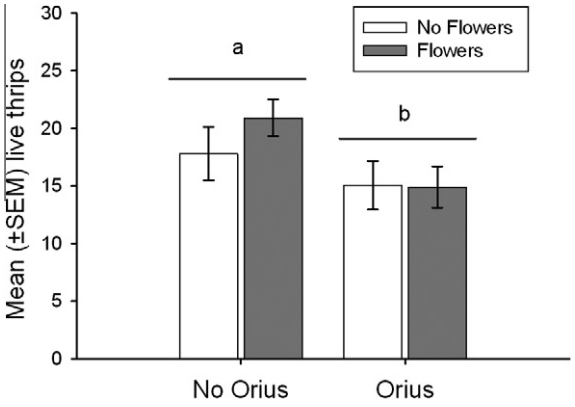

Fig. 4. Average number of thrips surviving when flowers and predators were present or absent. Different letters above horizontal bars indicate significant main effect of predator ($P < 0.05$).

urticae (18%), aphids (22%), and all other predators such as ladybeetle larvae, lacewings, and praying mantids (7%).

3.3. O. insidiosus predation in the presence and absence of Black Pearl pepper pollen

Twenty-three percent fewer thrips survived when predators were present ($F = 10.48$; df = 1, 48; $P = 0.0022$; Fig. 4). However, the presence of flowers did not have an effect on the number of thrips that survived ($F = 0.39$; df = 1, 48; $P = 0.5344$). There was not a significant interaction between flowers and predators ($F = 0.74$; df = 1, 48; $P = 0.3940$).

3.4. How spiders affect O. insidiosus retention on banker plants

At Hoffman Nursery, 50% fewer *O. insidiosus* remained on plants with spiders compared to plants without spiders ($F = 13.84$; df = 1, 57; $P = 0.0005$) (Fig. 5). There were fewer *O. insidiosus* recovered after 3 h than 1 h in either spider treatment ($F = 22.10$; df = 1, 57; $P \leqslant 0.0001$). The interaction between spider presence and time ($F = 0.01$; df = 1, 57; $P = 0.9372$) was not significant. In the Petri dish control experiment, 80% of spiders consumed *O. insidiosus* within one hour indicating Salticids are potential predators of *O. insidiosus*.

In the consumptive effects experiment, 35% fewer *O. insidiosus* were recovered on plants with spiders ($F = 15.68$; df = 1, 36 $P = 0.0003$; Fig. 5). There were 2.2 fewer *O. insidiosus* recovered after 3 h than 1 h ($F = 5.26$; df = 1, 36; $P = 0.0278$; Fig. 5). There was no significant interaction of spider presence and time ($F = 0.00$; df = 1, 36; $P = 0.9996$). In Petri dishes, 100% of spiders consumed *O. insidiosus* within one hour.

In the behavioral effects experiment, on average 0.85 fewer *O. insidiosus* were recovered on plants with spiders ($F = 3.85$; df = 1, 35; $P = 0.0578$; Fig. 5). There was no significant effect of time ($F = 2.88$; df = 1, 35; $P = 0.0987$) or an interaction of spider presence and time ($F = 2.25$; df = 1, 35; $P = 0.1425$) on *O. insidiosus* retention on banker plants. After 3 h, none of the spiders in Petri dishes had consumed any *O. insidiosus* confirming that glue effectively disabled spider mouthparts.

4. Discussion

One goal of banker plant systems is to improve augmentative biological control by sustaining populations of released natural enemies within a growing system (Frank, 2010). This study found that augmentation with released *O. insidiosus* was effective within

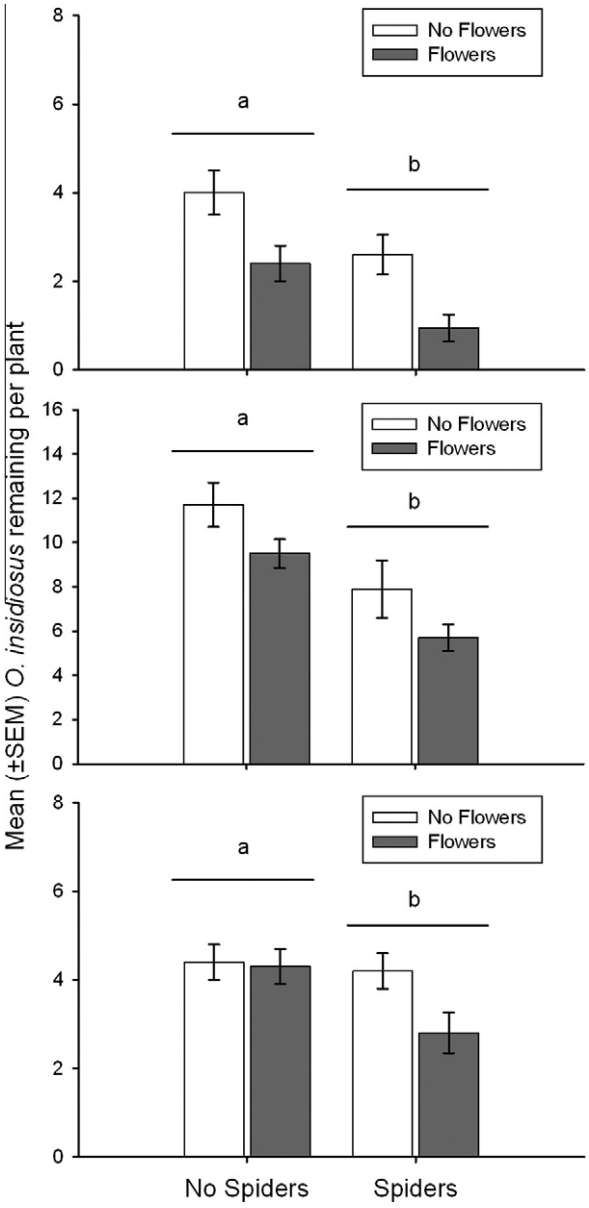

Fig. 5. (A) Average number of *O. insidiosus* recovered on banker plants at Hoffman Nursery. (B) Average number of *O. insidiosus* recovered on banker plants enclosed in a cage. (C) Average number of *O. insidiosus* recovered on banker plants with spiders with non-functioning mouthparts. Treatments are as follows: spiders absent, 1 h: (−)1; spiders absent, 3 h: (−)3; spiders present, 1 h: (+)1; spiders present, 3 h: (+)3. Different letters above horizontal bars indicate significant main effect of treatment ($P < 0.05$).

the complex growing system at Hoffman Nursery; however, the addition of banker plants in this unique nursery system did not increase *O. insidiosus* abundance or pest suppression. In fact, *O. insidiosus* were present in only 7% of total banker plant samples. Spiders were found in 82% of total banker plant samples, which disrupted biological control by restricting access to floral resources.

Black Pearl pepper banker plant pollen can increase female *O. insidiosus* longevity and size, nympal survival to adult, and abundance, as well as decrease nymphal development time (Wong, 2012). These positive effects on *O. insidiosus* life history could collectively contribute to sustaining or increasing *O. insidiosus* abundance in certain types of growing systems. In other cropping systems, floral resources can increase natural enemy abundance (White et al., 1995; Pineda and Marcos-Garcia, 2008; Jacometti

et al., 2010) and reduce emigration (Eubanks and Denno, 1999). However, at Hoffman Nursery there was no evidence that banker plants had any effect on *O. insidiosus* abundance or persistence in hoop houses. As such, we found no difference in pest suppression between augmentation and banker plant houses.

One concern when adding floral or other food resources to a cropping system is that they will distract or satiate predators thereby reducing consumption of pests. For example, additional plant resources decrease the number of pests killed by big-eyed bugs (Eubanks and Denno, 2000), lady beetles (Spellman et al., 2006), and carabids (Frank et al., 2011). However, predation rate is affected by several factors such as predator preference (Xu and Enkegaard, 2009), prey vulnerability (Lang and Gsodl, 2001), mobility (Baez et al., 2004), and density (Chow et al., 2008, 2010). Our study found that pollen did not reduce consumption of thrips by *O. insidiosus* adults. This may be because *O. insidiosus* and thrips both reside inside flowers and feed on pollen, so flowers should increase encounters between the two (Hansen et al., 2003). Thus, we do not feel that the presence of pollen on the banker plants accounts for why banker plants did not improve thrips suppression by *O. insidiosus* compared to augmentative release.

Higher-order predators can decrease natural enemy effectiveness by decreasing natural enemy foraging time (Wilder and Rypstra, 2004; Martinou et al., 2009), and decreasing fecundity (Meisner et al., 2010). Since spiders were found in 82% of banker plant samples, our second hypothesis as to why banker plants did not increase *O. insidiosus* efficacy at Hoffman Nursery was that spiders on banker plants were disrupting biological control by restricting access to floral resources by consuming or scaring away *O. insidiosus*. Importantly, spider abundance was similar in the crop samples from augmentation, banker plant, and control houses. Thus, banker plants appear to have provided an addition opportunity for predation of *O. insidiosus* that was not present in other houses. Spiders, including those in Salticidae, Lycosidae, and Oxyopidae families, consume a wide variety of prey, which including hemipteran predators (Nyffeler et al., 1987; Hodge, 1999; Nyffeler, 1999; Finke and Denno, 2003, 2005). Spiders also restrict floral resources to other beneficial insects like honeybees, which are less likely to visit flowers where crab spiders are present (Reader et al., 2006).

In our study, spiders significantly decreased *O. insidiosus* retention on Black Pearl pepper banker plants. The presence of spiders reduced *O. insidiosus* abundance on banker plants by 46% and 36% in the Hoffman Nursery and consumptive effects experiments respectively. From these results, we can infer that spiders on banker plants restricted access to floral resources by consuming *O. insidiosus*. Thus, banker plants in this system could have been a sink for *O. insidiosus* populations. Sit-and-wait predators, like Oxyopids and other top-predators, can decrease biological control efficacy by consuming intermediate-predators, such as *O. insidiosus*, and relieving pests from pressure of intermediate predators (Rosenheim et al., 2004). Even though the spider families we used in our experiments contain many species with different behaviors and preferences we did not identify spiders to species. Thus using one species may have made the effect on *O. insidiosus* stronger or weaker. However, we observed many different species in the experimental hoop houses and hoped to recreate the effect of a diverse spider community rather than determine the effect of a single species.

Although we did not test this hypothesis, another reason why banker plants did not improve augmentation biological control may have been that *O. insidiosus* emigrated from hoop houses at Hoffman Nursery. Sides of the hoop-houses are rolled up in the summer to decrease temperatures within houses. Also, Hoffman has planted flower beds to attract natural enemies and maintains grass cropping beds outside of hoop-houses. *Orius* spp. is naturally found in diverse field borders (Atakan, 2010) and, as a generalist, benefit from a diverse set of prey and plant material (Root, 1973). *O. insidiosus* may have left houses to search for other plant or prey food in the surrounding vegetation. Although attraction to surrounding vegetation should have been similar in banker plant and augmentation houses, the presence of spiders on banker plants in combination with dense flower beds may have created a 'push–pull' effect (Cook et al., 2007) that increased *O. insidiosus* emigration from banker plant houses. In addition, natural areas and crops outside of the houses may have caused a constant influx of thrips that was greater than any difference in thrips suppression between augmentation and banker plant houses.

This is the first study to test the Black Pearl pepper banker plant and *O. insidiosus* system for biological control. The first goal of this study was to determine how or if Black Pearl pepper banker plants were contributing to pest suppression by *O. insidiosus* at Hoffman Nursery. We found that augmentation biological control by *O. insidiosus* does work in a complex growing system like Hoffman Nursery, but banker plants do not further improve pest suppression compared to augmentative releases alone. The Black Pearl pepper banker plant system is popular among greenhouse and nursery growers alike, however this system was complicated by spiders and *O. insidiosus* emigration in the open environment at Hoffman Nursery. As such we cannot recommend it to growers with open systems and would encourage future research to be conducted in a more controlled growing system. Many other aspects of this system require future study such as whether pollen attracts or otherwise increases thrips abundance and the distance *O. insidiosus* emigrate from banker plants into crops. Nonetheless our experiments suggest that enclosed greenhouses would reduce immigration by spiders and emigration by *O. insidiosus*, forcing the pirate bugs to utilize floral resources provided by banker plants and allowing them to access these resources by excluding immigrating top predators such as spiders.

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