The Feeding Behavior of the Bigeyed Bug, Minute Pirate Bug, and Pink Spotted Lady Beetle Relative to Main Strawberry Pests

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ABSTRACT Laboratory assays were performed to determine the impact of three predators, the bigeyed bug, *Geocoris punctipes* Say, minute pirate bug, *Orius insidiosus* (Say), and the pink spotted lady beetle, *Coleomegilla maculata fuscilabris* (Mulsant), on two herbivores, the cotton aphid, *Aphis gossypii* Glover, and the twospotted spider mite (TSM), *Tetranychus urticae* Koch, using strawberry (*Fragaria ananassa* Duchesne) leaflets as a substrate. Both herbivores are considered important strawberry pests worldwide. Daily and hourly consumption of a single prey species studied were conducted as well as a preference for prey test. All stages of the bigeyed bug, minute pirate bug, and pink spotted lady beetle fed on the cotton aphid and TSM. The pink spotted lady beetle had a higher rate of consumption for both the cotton aphid and TSM, and therefore, may be a more effective predator of both prey species. The bigeyed bug and minute pirate bug (third instar and adult) prefer TSM over cotton aphids based on handling time. In contrast, the pink spotted lady beetle (third instar and adult) prefers aphids over mites. Results from these experiments indicated that the pink spotted lady beetle seems to be a good predator to incorporate into an existing biological control program for cotton aphid and TSM on strawberries. Better understanding of these three predators will lead to their more efficient use for biological control of aphids and TSM.

KEY WORDS aphids, *Coleomegilla*, *Geocoris*, *Orius*, twospotted spider mite, predators

THE STRAWBERRY, *Fragaria ananassa* Duchesne, is an intensively cultivated, high-value crop that requires large inputs of chemicals, including insecticides and miticides. Wherever strawberries are grown, >50 invertebrates and diseases affect both quality and yield of the crop (Howard et al. 1985, Metcalf and Metcalf 1993); however, only a handful of these pests cause significant yield losses. The twospotted spider mite (TSM), *Tetranychus urticae* Koch (Acari: Tetranychidae), and the cotton aphid, *Aphis gossypii* Glover (Homoptera: Aphididae), are two of the most important strawberry pests worldwide (Helle and Sabelis 1985, Howard et al. 1985, Leclant and Deguine 1994). Success has been achieved in reducing the threat from TSM in the field and greenhouse by the introduction of *Phytoseiulus persimilis* Athias-Henriot onto the strawberry crop when ~5–10% of the strawberry leaflets have been infested with ≥1 mite (Van de Vrie and Price 1994). Natural enemies also are important in the control and regulation of the cotton aphid. The use of parasitic wasps such as *Aphidius colemani* L. is known to provide good aphid control (Van Driesche and Bellows 1996).

Other predators also play an important role in controlling the cotton aphid and TSM. However, information on their ability to locate and consume prey is needed to use them effectively as biological control agents in integrated pest management (IPM) systems (Stern et al. 1959, Lingren et al. 1968). Hoy (1994) indicates that the efficacy of predators can be improved as we gain a greater understanding of their feeding behavior and the way they relate to herbivores.

Relatively extensive information exists regarding the biology and ecology of generalist predators in various environments (Metcalf and Metcalf 1993, Sabelis and Van Rijn 1997, Rosenheim 1998); however, information concerning the feeding behavior of the bigeyed bug, *Geocoris punctipes* Say (Heteroptera: Lygaeidae) (Champlain and Sholdt 1967, Stoner 1970, Cohen 1985), the minute pirate bug, *Orius insidiosus* (Say) (Heteroptera: Anthocoridae) (Askari and Stern 1972, Al-Deeb et al. 2001), and the pink spotted lady beetle, *Coleomegilla maculata* DeGeer (Coleoptera: Coccinellidae) (Wright and Laing 1980, 1982, Groden et al. 1990), relative to strawberry pests, has not been widely reported. In general, these predators often consume large numbers of prey and are recognized as predators of mites, whiteflies, thrips, and aphids (Howard et al. 1985, Van Driesche and Bellows 1996). The pink spotted lady beetle, considered polyphagous

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rather than aphidophagous, also feeds on soft-bodied insects such as mealybugs, scales, and whiteflies (Griffin and Yeargan 2002). The bigeyed bug feeds on a wide variety of prey such as flea beetles, larvae and eggs of various insects, European mites, and aphids (Stoner 1970). The minute pirate bug preys mostly on caterpillar eggs, aphids, psyllids, and thrips (Ruth and Dwumfour 1989, Kagai 1995).

The feeding behavior of the bigeyed bug, minute pirate bug, and pink spotted lady beetle was studied using the cotton aphid and TSM. These predators were selected because they are commercially available and highly recommended for mite and aphid control. The objectives of this research project were to ascertain whether the bigeyed bug, minute pirate bug, and pink spotted lady beetle consume cotton aphid and TSM on strawberry and to determine which pest is the preferred prey of each predator. With this information, we can predict the potential of the bigeyed bug, minute pirate bug, and pink spotted lady beetle to reduce populations of the cotton aphid and TSM on strawberries produced in the greenhouse or in the field. Questions such as number of prey consumed, efficiency of predators, and preference of prey species were answered.

Materials and Methods

Experiments were performed at the biological control laboratory of the Protected Agricultural Project Research Station, Horticultural Sciences Department of the University of Florida in Gainesville, Florida. The feeding behaviors of the bigeyed bug, minute pirate bug, and pink spotted lady beetle were studied in a series of laboratory experiments. All predators tested, reared on artificial diet, were provided by Entomos, a local insect supplier (Gainesville, FL). The cotton aphid and the TSM were used as prey in all the feeding behavior experiments. The cotton aphid and TSM colonies were maintained on strawberry and bean plants, respectively, in separate greenhouses.

Daily Consumption of a Single Prey Species

A series of experiments was conducted to determine the consumption of the cotton aphid and TSM by the bigeyed bug, minute pirate bug, and pink spotted lady beetle. Each experimental unit consisted of a 5-cm-diameter petri dish (Fisherbrand, Suwanee, GA) in which was placed one strawberry leaflet, one individual of a single predator species, and 10 individual prey (cotton aphid or TSM). Instars and adults of the bigeyed bug and pink spotted lady beetle were tested; only the second- and fourth-instar nymphs and adults were studied for the minute pirate bug. All the predator individuals tested were starved for 8 h before provided with either cotton aphid or TSM for 5 d. Ten individual prey per petri dish, without a host, served as a control for each experiment. Aphids and mites were removed from infested leaves in the colony using a wet camel hair brush no. 0. The strawberry leaflets were isolated with lanolin to confine the prey on the upper side of the leaf. Petri dishes were sealed with Parafilm and labeled. Each experiment was maintained at 21–23°C, 60–65% RH, and a 16 L:8 D photoperiod. Samples were examined under a stereo microscope, and number of prey consumed per day was recorded as well as the cumulative number of prey consumed. Each experiment was repeated three times, with five replications per treatment in a split block design.

Hourly Consumption of a Single Prey Species

Using the same methodology as above, the third instar or adult of each predatory species was exposed to 10 individuals of a single prey species. The numbers of cotton aphids or mites consumed each hour for 12 h and after 24 h were recorded. Each experiment was repeated three times, with five replications per treatment. The control consisted of 10 individual prey without a predator.

Preference for Prey Species

Aphids and mites were offered to the third instar and adult of each predator species using the methodology as in the previous experiments. The experimental unit consisted of a 10-cm-diameter petri dish with a strawberry leaflet, 10 aphids, 10 TSM, and an individual of a single predator species. The time required to handle a prey and the number of prey eaten in 24 h were recorded. Handling time was defined as the time used by the predator to locate, restrain, and feed on the prey, but not necessarily to kill it; this was used as a measure of preference (Steward et al. 2002). The experiment was repeated three times, with five replications per treatment. The control treatment consisted of 10 cotton aphids and 10 TSM without a predator.

Data Analysis. Data on the number of prey consumed were analyzed with SAS software (SAS Institute 2000). The general linear model (GLM) procedure was used to construct analysis of variance (ANOVA). The prey preference data were analyzed by χ^2 tests. All data are presented as average number ($\pm$SE) of prey consumed by a predator per day. Least significant difference (LSD) values ($\alpha = 0.05$) also were determined.

Results

Daily Consumption of a Single Prey Species

Aphid Consumption. The cumulative average numbers of cotton aphids consumed by three species of predators are presented in Table 1. The data recorded in the 5-d feeding trial indicate that the pink spotted lady beetle has a higher consumption rate compared with the bigeyed bug or minute pirate bug (LSD 0.05 = 1.08; $F = 1.32$; df = 4,20; $Pr > 0.083$). Aphid consumption by the pink spotted lady beetle on day 1 was significantly different among instars (LSD 0.05 = 1.91; $F = 1.84$; df = 4,20; $Pr > 0.061$). No differences

Table 1. Cumulative consumption (mean ± SE) by three species of predators of the melon aphid, *A. gossypii* Glover, and the twospotted spider mite, *T. urticae* Koch, during a 5-d feeding period

Predator species	Life stage	Number consumed[a]	
		A. gossypii	*T. urticae*
G. punctipes ($n_o = 10^b$)	First nymph	9.0 ± 0.5	8.4 ± 1.2
	Second nymph	8.5 ± 0.5	10.0 ± 0.0
	Third nymph	8.4 ± 1.0	9.6 ± 0.3
	Fourth nymph	6.0 ± 1.4	9.8 ± 0.2
	Fifth nymph	5.7 ± 1.1	8.8 ± 0.5
	Adult	8.4 ± 0.4	9.8 ± 0.2
O. insidiosus ($n_o = 10^b$)	Second nymph	8.8 ± 1.0	10.0 ± 0.0
	Fourth nymph	9.2 ± 1.1	9.6 ± 0.3
	Adult	7.6 ± 0.8	9.6 ± 0.4
C. maculata ($n_o = 10^b$)	First instar	10.0 ± 0.0	9.6 ± 0.4
	Second instar	10.0 ± 0.0	10.0 ± 0.0
	Third instar	10.0 ± 0.0	10.0 ± 0.0
	Fourth instar	10.0 ± 0.0	10.0 ± 0.0
	Adult	10.0 ± 0.0	10.0 ± 0.0
Control		0.0 ± 0.0	0.0 ± 0.0

[a] Means (± SE) within species. Each treatment was repeated three times with five replications per treatment.
[b] n_o = initial number of prey.

were observed on days 2–5. At the end of the 5-d trial, all prey were consumed.

On day 1, there were no significant differences in consumption among first, second, and third instars and adults of the bigeyed bug (LSD 0.05 = 2.5; $F = 2.04$; df = 5,20; $Pr > 0.1269$). Similar trends were observed on days 2–5. On day 5, the fourth and fifth instars consumed the least number of aphids (6.0 ± 1.4 and 5.7 ± 1.1, respectively; LSD 0.05 = 2.5; $F = 2.12$; df = 5,20; $Pr > 0.0169$).

The number of aphids consumed by the minute pirate bug fourth instars was significantly greater compared with second instars or adults on day 1 (LSD 0.05 = 3.6; $F = 4.63$; df = 2,12; $Pr > 0.1269$). After day 1, no significant differences were observed among instars. By day 5, the minute pirate bug adults had consumed the least number of aphids (7.6 ± 0.8; LSD 0.05 = 2.7). On day 5, the number of aphids without a predator (control) increased considerably (35.0 ± 3.2).

Mite Consumption. The cumulative average number of TSM consumed by three species of predators is presented in Table 1. The data recorded in the 5-d feeding trial indicates that the pink spotted lady beetle has a significantly higher consumption rate compared with the bigeyed bug or minute pirate bug (LSD 0.05 = 1.23; $F = 1.18$; df = 4,20; $Pr > 0.583$). All the pink spotted lady beetle instars, with the exception of the first instar (9.6 ± 0.4), consumed all the prey offered by day 5. Excluding day 1, there were no significant differences among instars the second, third, fourth, and fifth days.

The bigeyed bug second instar consumed all mites offered by the end of the trial. By day 5, the first and fifth instars consumed the least number of mites (8.4 ± 1.2 and 8.8 ± 0.5, respectively).

The minute pirate bug second instar had consumed all prey by the end of the 5-d trial. On day 5, third instars and adults consumed most of the prey (9.6 ± 0.4 and 9.6 ± 0.3, respectively). The number of mites without a predator (control) increased.

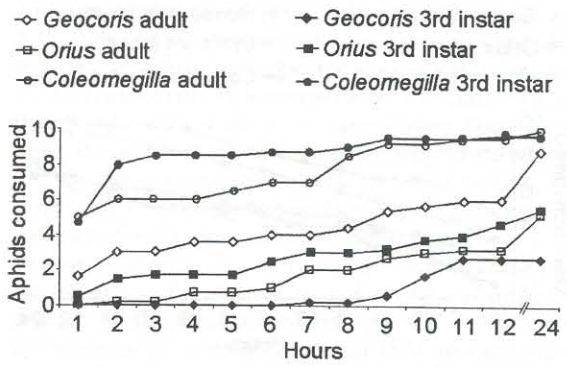

Fig. 1. Cumulative hourly consumption (mean ± SE) of the melon aphid, *A. gossypii* Glover, by the third instars and adults of three predator species.

Hourly Consumption of a Single Prey Species

Aphid Consumption. The bigeyed bug third instar did not consume any aphids in the first 6 h of being exposed to the prey (Fig. 1). After 6 h, the hourly consumption increased slightly, reaching 27% (2.7 ± 1.3) at 12 h. Not all the prey offered were consumed. The bigeyed bug adults consumed more aphid prey compared with the third instars. Feeding began within 1 h after the predator was exposed to the prey and reached close to 60% (6.0 ± 2.4) at 12 h.

The minute pirate bug third instars consumed 5% (0.5 ± 0.2) of the aphids 1 h after being exposed to the prey (Fig. 1). At 12 and 24 h, 47 (4.7 ± 2.2) and 53% (5.3 ± 1.8), respectively, of the prey were consumed by the third instars. The minute pirate bug adults delayed feeding for 2 h after being exposed to the cotton aphid (0.2 ± 0.1). At 12 and 24 h, 32 (3.2 ± 1.8) and 51% (5.1 ± 1.6) of the prey were consumed.

The pink spotted lady beetle third instar consumed 47% of the aphids after 1 h (4.7 ± 2.2; Fig. 1) of exposure to the prey. After 2 h, the rate of consumption reached 80% (8.0 ± 2.9). At 12 and 24 h, 97 (9.7 ± 3.1) and 97% (9.7 ± 3.1), respectively, of the aphid prey were consumed. The pink spotted lady beetle adults fed at a slower rate compared with third instars; however, at 12 and 24 h, 95 (9.5 ± 3.1) and 100% (10.0 ± 0.00), respectively, of the aphid prey were consumed.

Mite Consumption. The bigeyed bug third instars consumed mites immediately after being exposed to the prey (Fig. 2). The hourly increment of consumption was steady, reaching 69% (6.9 ± 1.5) at 12 h. Not all of the prey were consumed by the third instars at the end of the feeding period. During the first 6 h, bigeyed bug adults ate more TSM than third instars consumed. Feeding started within 1 h of the predator being exposed to the prey, and after 24 h, the bigeyed bug adults had consumed 75% (7.5 ± 2.3) of the mites.

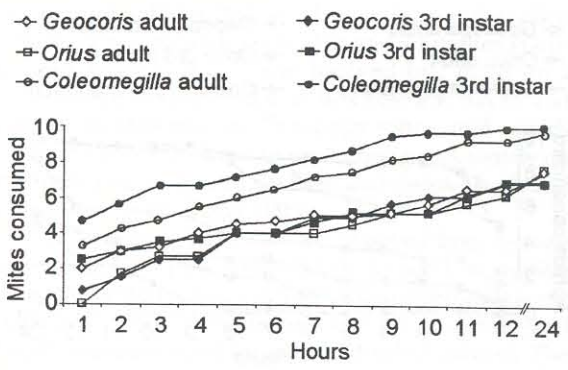

Fig. 2. Cumulative hourly consumption (mean ± SE) of the twospotted spider mite, *T. urticae* Koch, by third instars and adults of three predator species.

The minute pirate bug third instars consumed 25% (2.5 ± 0.2) of the mites offered in 1 h of exposure to the prey (Fig. 2). At 12 and 24 h, 70% (7.0 ± 2.1 and 7.0 ± 2.3, respectively) of the prey were consumed. The minute pirate bug adults delayed feeding until 2 h after being exposed to the prey (1.7 ± 0.4). At 12 and 24 h, 62 (6.2 ± 2.8), and 77% (7.0 ± 2.2) of the mite prey were consumed by adult minute pirate bugs.

The pink spotted lady beetle third instar consumed 47% (4.7 ± 2.4; Fig. 2) of the prey within the first hour of exposure to the TSM. After 5 h of being exposed to the prey, 72% were consumed (7.2 ± 2.2). After 12 h, all of the prey were consumed by third-instar pink spotted lady beetles. Adult pink spotted lady beetles fed at a slightly slower rate compared with third-instar pink spotted lady beetles; however, at 12 and 24 h, 93 (9.3 ± 3.1) and 98% (9.75 ± 2.20), respectively, of the prey were consumed.

Preference for Prey Species. The third-instar bigeyed bug and minute pirate bug spent less time handling TSM compared with the handling time for cotton aphid (Table 2). Both predators began consuming the mite prey within a few minutes of exposure (LSD 0.05 = 1.43; $F = 1.45$; df = 4,20; $Pr > 0.381$). After 24 h, both predators had consumed more TSM than aphids. The bigeyed bug and minute pirate bug (third instar and adult) did not consume all of their prey; however, the feeding injury was sufficient to disable the prey. The pink spotted lady beetle (third instar and adult) seems to have a preference for the cotton aphid over TSM. The handling time was significantly less ($P <$ 0.05) for aphids than for TSM. After 24 h, the pink spotted lady beetles consumed more aphids (9.0 ± 1.3 and 8.9 ± 1.5, third instar and adult, respectively) than TSM (8.3 ± 1.3 and 7.9 ± 1.8, third instar and adult, respectively).

Discussion

All stages of the bigeyed bug, minute pirate bug, and pink spotted lady beetle consumed cotton aphids and TSM under laboratory conditions. The pink spotted lady beetle may be the most efficacious of the predators against cotton aphid and TSM. Prey consumption was higher and handling time was less for the pink spotted lady beetles compared with the bigeyed bug and minute pirate bug.

This type of bioassay mimics interactions between predators and herbivores that occur in the outer commercial fields. We believe that laboratory assays could give insight about the feeding capability of this predator if we were to study the individual compared with the population. In laboratory studies where the predator is confined with the prey, the results of prey consumption and handling time may not relate directly to the predator behavior in the greenhouse or field.

In the United States, control of aphids and mites in commercial strawberry fields relies mainly on registered miticides (Helle and Sabelis 1985, Van de Vrie and Price 1994); however, biological control offers an ecological mode of pest control (Van de Vrie and Price 1994). Data from our research indicate that greenhouse grown crops, including vegetables and small fruits, will benefit from the use of generalist predators such as the bigeyed bug, minute pirate bug, and pink spotted lady beetle (Rondon et al. 2003).

The bigeyed bug is an important predator of eggs and larvae of most caterpillars (Bell and Whitcomb 1964, Lingren et al. 1968, Ali and Watson 1982); however, their status as aphid and mite feeders on strawberry is still uncertain. Results from our daily and hourly consumption studies indicate that the cotton aphid and TSM may not be the preferred prey of the bigeyed bug; however, this predator could contribute to a reduction in both prey species populations (Table 1). Regarding their efficiency, Hagler and Cohen (1991) acknowledge that, because of their small size and cryptic nature, the efficiency of the bigeyed bug behavior is difficult to determine.

Table 2. Handling time and number of prey consumed in 24 h by third-instar and adult predators when provided a choice of two species of prey

	Prey species	*G. punctipes*		*O. insidiosus*		*C. maculata*	
		Third instar	Adult	Third instar	Adult	Third instar	Adult
Handling time (min)[a]	*T. urticae*	5.6 ± 2.3	5.9 ± 3.3	7.2 ± 3.1	7.8 ± 3.4	6.2 ± 2.1	4.5 ± 2.3
	A. gossypii	6.8 ± 4.2	6.3 ± 2.9	12.5 ± 5.4	9.3 ± 4.1	2.2 ± 2.0	3.1 ± 1.8
Prey eaten after 24 h[a] ($n_o = 10$)[b]	*T. urticae*	5.5 ± 2.1	5.4 ± 2.3	7.8 ± 2.3	8.0 ± 2.1	8.25 ± 1.3	7.9 ± 1.4
	A. gossypii	4.3 ± 2.2	3.5 ± 2.1	4.5 ± 1.8	5.7 ± 1.8	9.02 ± 1.3	8.9 ± 1.5

[a] Each treatment was repeated three times with five replications per treatment.
[b] n_o = initial number of prey.

Unpublished data in the greenhouse indicated that the bigeyed bug aggregates around the auxiliary buds in the strawberry plants, consuming any prey they may encounter. The bigeyed bug also was observed piercing young strawberry leaves and auxiliary buds; however, no injury was apparent. This phytophagous behavior was previously evaluated by Lingren et al. (1968) in cotton. Stoner (1970), Yokoyama (1980), and Naranjo and Stimac (1985) believe that this phytophagous behavior increases the possibility of the bigeyed bug persistence in the field when prey items are scarce.

Previous research also indicates that phytophagous feeding behavior could be used for augmentative programs. However, in a large scale augmentative program for melon aphid or TSM control, releases of the bigeyed bug would not be recommended based on the data from our laboratory studies. Although bigeyed bugs consumed both the cotton aphid and TSM, the adults required 9 h to consume 50% of the melon aphids and 24 h for the third instar or adults to consume 50% of the mites offered (Fig. 2). At the end of a 5-d trial, the bigeyed bug did not consume all aphids or TSM presented (Table 1). This creates concerns regarding resurgence of the pests, because aphids and mites generally have a greater reproductive rate compared with their natural enemies (Ruth and Dwumfour 1989, Van Driesche and Bellows 1996).

Like the bigeyed bug, the minute pirate bug also is considered an efficient predator of small caterpillars in addition to thrips (Kagai 1995), spider mites, insect eggs, and aphids (Askari and Stern 1972). The efficacy of the minute pirate bug as a cotton aphid or TSM feeder using strawberry as a substrate has not been thoroughly discussed in previous research. Our results indicated that, although the minute pirate bug did consume cotton aphids and TSM, they were not efficient at reducing both prey populations in the laboratory assays. Moreover, they left prey unconsumed. The low survivorship of the minute pirate bug immature and adult stages made observations difficult; this mortality was more likely caused by their sensitivity to low humidity (Glenister 1998, Al-Deeb et al. 2001). When strawberry plants were observed, the minute pirate bug was found close to the base of the petioles where droplets of water accumulate, making the microenvironment more humid (unpublished data).

Adult and third-instar minute pirate bug consumed only 50% of the aphids 24 h after being exposed to the prey, and third instar and adults consumed 50% of the TSM at 8 and 9 h, respectively, after exposure to the mites. The minute pirate bug does not seem to be an efficient predator of either the cotton aphid or TSM, and its contribution to reducing cotton aphid or TSM populations on strawberry in the greenhouse or field may be limited.

The pink spotted lady beetle seems to be an effective predator of both cotton aphid and TSM (Table 1). The aphid and mite consumption rate for pink spotted lady beetle was greater compared with the bigeyed bug or minute pirate bug. The third-instar pink spotted lady beetle consumed almost 50% of the aphids after 2 h of exposure to the prey and almost 90% 1 h later. Although some commercial insectaries recommend releases of adult pink spotted lady beetle for pest control, especially in a greenhouse, our data indicate that third instar is the most appropriate stage to be used, despite that there was no significant difference in the consumption rates among instars tested. The pink spotted lady beetle third instar is more voracious compared with first and second instars, which are delicate and difficult to handle, and more reliable than the fourth instar, which in a few days is ready to pupate. Adult pink spotted lady beetles are excellent predators of the cotton aphid and TSM, but according to our observations, when the adult pink spotted lady beetles are released, they may leave the field. The pink spotted lady beetle seems to be a good predator to incorporate into an existing biological control program for cotton aphid and TSM on strawberries.

Our study has increased the understanding of the relationship among the strawberry, its cotton aphid and TSM pests, and important biological control agents. This study provides a basis for a biological control of cotton aphid and TSM component of a comprehensive integrated strawberry pest management program. Further studies are needed regarding the potential use of kairomones to attract adult pink spotted lady beetles and to assure their permanence in the field. The interaction of the bigeyed bug, minute pirate bug, and pink spotted lady beetle in the greenhouse and the field as well as the number of each predator species needed to reduce cotton aphid and TSM populations on strawberry requires further evaluation. Better understanding of these characteristics will lead to more efficient use of these predators for biological control of the cotton aphids and TSM.

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