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Lacewings (*Mallada basalis*) and minute pirate bugs (*Buchananiella whitei*) as potential biocontrol agents of western flower thrips (*Frankliniella occidentalis*) in strawberries: predation on different thrips stages in no-choice and choice tests

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Abstract

The strawberry (*Fragaria* × *ananassa*) is a significant economic crop in New Zealand, but has recently suffered substantial damage from western flower thrips (*Frankliniella occidentalis*), resulting in significant financial losses. This study first assessed the predation ability of two commercially available predatory insects, the green lacewing, *Mallada basalis* (first-instar larvae) and *Buchananiella whitei* (adults), on western flower thrips nymphs and adults under no-choice conditions in a laboratory setting. Next, the preferences of the two predatory insects for different life stages of the thrips were tested in the same laboratory setting under choice conditions. In no-choice test, both predator species consumed the highest number of first instar thrips nymphs, second highest the second instar thrips nymphs, and the lowest the thrips adults. In choice test, both predator species ate significantly fewer thrips adults than immature life stages; further analysis of Manly index confirmed the lowest preference for thrips adults by both predator species. This study provides the first insight into the potential of these two predatory insect species for biocontrol against western flower thrips. The potential of these two predator species in controlling western flower thrips on strawberries should be further tested in greenhouses or field plots to better understand their roles in integrated pest control systems.

Key words: Predator-prey ecology, prey preference, Manly index, biological control

Introduction

Strawberry (*Fragaria* × *ananassa*) is a significant economic crop worldwide. Global strawberry production increased from 7.6 to 8.9 million tonnes from 2014 to 2019 (Lahiri *et al.* 2022). Strawberries account for 47.6% of all berries produced in New Zealand (Timudo-Torrevilla *et al.* 2005). Strawberries contain substances such as vitamin C, folic acid, and phenols, which can provide bioactive compounds to the human body (Timudo-Torrevilla *et al.* 2005). They can also provide unsaturated fatty acids, dietary fibre, and other substances that contribute to human health (Proteggente *et al.* 2002).

Common pests that cause economic loss to strawberries include thrips, mites, and aphids. Thrips are one of the most common pests that damage strawberries and many other crops (Lahiri *et al.* 2022). They are very difficult to control due to their small size and strong reproductive capacity. They can reduce the yield of strawberry crops by feeding on leaves, flowers, and fruits (Lahiri *et al.* 2022). They can also cause problems such as bronzing and cracking in strawberries (Panthi *et al.* 2021; Strzyzewski *et al.* 2021). Furthermore, they can act as vectors for tomato spotted wilt virus (Mound 2002).

The western flower thrips, *Frankliniella occidentalis* (Pergande, 1895) (Thysanoptera: Thripidae), is a common pest of strawberries worldwide (Strzyzewski *et al.* 2021). Its mandibles are adapted for piercing and sucking, allowing this species to damage strawberry plants by feeding on leaves, flowers, and fruit, resulting in reduced crop quality (Hunter & Ullman 1989). It is widely distributed in various regions of New Zealand (Teulon & Nielsen 2005).

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Although insecticides can effectively reduce thrips populations in a short term, their repeated use may lead to the development of insecticide resistance. In addition, consumers are increasingly concerned about pesticide residues on fruit. Therefore, adopting an integrated thrips management approach that combines biological control agents with appropriate or selective spray of pesticides is necessary.

Current commonly used biological control agents for western flower thrips include: i) predatory mites, which mainly target thrips nymphs (especially first-instar nymphs); ii) minute pirate bugs, which can prey on both thrips nymphs and adults; iii) soil-dwelling predators, which can prey on the thrips' pupae that fall from plants in the soil (Mouden *et al.* 2017).

Green lacewings (Neuroptera: Chrysopidae) are polyphagous predators that can prey on aphids, whiteflies, small caterpillars, thrips and others (Sarkar *et al.* 2019; Ntalia *et al.* 2022). Among them, *Mallada basalis* (Walker, 1853) (Neuroptera: Chrysopidae) is a species of green lacewing whose larvae can prey on a variety of pests, including cotton mealybug, spider mites and others (Chen *et al.* 2014; Zhou *et al.* 2021). Relatively little has been published about its biocontrol potential against thrips, although this species is already being commercially produced in large quantities by a biocontrol company in New Zealand.

Minute pirate bugs (Hemiptera: Anthocoridae) are predatory insects and currently a common group of biological control agents. These omnivorous insects can feed on various small arthropods, pollen, and plant sap (Salas-Aguilar & Ehler 1977; Coll 1998; De Clercq *et al.* 2023). Most species in this family can prey on piercing-sucking pests such as thrips, mites, aphids and mealybugs (Ballal *et al.* 2023). *Buchananiella whitei* Reuter, 1884 is a lesser-known species of minute pirate bug and has rarely been studied before for its role in biological control of pest in New Zealand, although it is now also being commercially bred in significant quantities by a biocontrol company in New Zealand. A previous study found that *B. whitei was* one of the predator species in the unsprayed field in association with *Thrips tabaci* (Lindeman, 1889) (Workman & Martin, 2002).

This study aimed to test the predation ability of green lacewing larvae (*M. basalis*) and adult minute pirate bugs (*B. whitei*) on different life stages of western flower thrips under controlled laboratory conditions. It used no-choice and choice experiments. The no-choice experiments tested the ability of lacewing larvae (first instar) and adult minute pirate bugs (*B. whitei*) to prey on a single life stage of western flower thrips. The choice experiments tested the ability of these two predator species to selectively attack different life stages of western flower thrips when a mixture of life stages was offered together. This study is one of a series experiments designed to understand the potential of these two predator species in biological control of western flower thrips in strawberries.

Material and methods

Thrips sources

Strawberry flowers (especially those suspected to carry western flower thrips inside) were collected from West Auckland: Good Planet on several occasions in February, March, April, and May 2025; Zakberry Strawberry Farm on two occasions in April 2025.

The thrips and associated flowers were temporarily placed in a round, transparent plastic bucket with a bottom diameter of approximately 10 cm, a top diameter of approximately 15 cm, and a height of approximately 15 cm. The lid of the bucket was cut with scissors, leaving a square hole (5 cm each side) in the middle of the lid for ventilation. After adding the collected flowers to the bucket, the bucket was covered with a fine mesh, which was dense enough to prevent thrips from entering/escaping. The mesh and hole in the lid provided air circulation for the thrips inside and also prevented them from escaping.

When handling/processing thrips in the laboratory, a special cage was used. The cage was rectangular, measuring 50 × 50 ×70 cm (length × width × height). It had mesh on the bottom and top, and three of the four vertical sides were meshed, one with a zipped opening. The cage was supported by iron pipes.

Plastic buckets containing flowers/thrips were gently poured into the cage. The thrips would disperse from the flowers. All handling and treatment of thrips were done inside the cage to minimize their escape.

Identification of western flower thrips

Five adult thrips were prepared in a glass slide temporary mounts using Hoyer's Medium (Mound & Walker 1982) and heated in an oven at 60 °C for 1 hour for a quick check and at 40 °C for up to 6 weeks for final identification. Slides were studied using a Nikon i90 microscope (Coherent Science, Queensland, Australia). Keys and species concepts

follow Mound & Walker (1982) and Mound *et al.* (2017). Voucher specimens housed at the Bioeconomy Science Institute were used for comparison as needed.

Cultivation of western flower thrips

To obtain a continuous supply of all life stages of western flower thrips, we established a rearing system similar to that described in DeGraaf & Wood (2009). We prepared plastic boxes, each 20 cm long, 15 cm wide, and 5 cm high, containing four snow pea pods (purchased from Woolworths St. Johns supermarket in Glen Innes, Auckland, and Taiping Asian Supermarket in Wairau). We placed collected strawberry flowers with western flower thrips in the boxes, covered them with a 120-mesh nylon, and then sealed the boxes with a vented lid to prevent the thrips from escaping. We placed the boxes in a room with a temperature of 25°C ± 1°C, relative humidity of 40%, and a day-night cycle of 16 hours light: 8 hours dark. After approximately three days, we removed the strawberry flowers. If the snow pea pods became moldy or rotten, we replaced them with new pods. Every 3 days, we added frozen pollen from the bulrush/rāupo (*Typha orientalis* C.Presl) to the rearing box from the laboratory freezer (at –18 °C) for providing food to thrips adults.

Predator preparation

The lacewing larvae and minute private bugs were purchased from Bioforce Ltd, Karaka, South Auckland. The frozen moth eggs (*Ephestia kuehniella* Zeller, 1879) used for rearing both predators were also purchased from the same company.

The newly purchased lacewings were in their egg form. Many of these oval eggs were held in place on a white mesh screen by a thin, white egg stalk. Some eggs were green, while others—which were about to hatch—were off-white. We used small cylindrical vials (diameter 1 cm; height 4 cm) to incubate the lacewings. These vials' lids were pierced with insect pins with small holes to allow ventilation. We used small tweezers to snip the egg stalk of a lacewing egg, remove the egg from the mesh, and place it in a vial. Between 10 and 20 moth eggs were then added to each vial as food for the soon-to-hatch lacewing larva. Then, the lid was closed. To prevent cannibalism, only one lacewing egg was placed in each vial. 50 vials with individual lacewing eggs were prepared to ensure sufficient lacewing larvae for predation experiments.

We placed the vials in a plastic box that was placed in a room maintained at a temperature of 25°C ± 5°C, a relative humidity of 50%–60%, and a photoperiod of 16 hours light: 8 hours dark. Each vial was observed daily until the lacewing larvae appeared and were ready for predation experiments. To control for the effect of larval size on the predation results, we used only first-instar lacewing larvae that were no more than two days old. No food was provided during this period, other than the initial moth eggs. Since this experiment only involved first-instar lacewing larvae, fresh lacewing eggs were purchased several times during the experimental period.

The newly purchased minute pirate bugs were in their immature stages, which were reared a plastic box (20 cm long, 15 cm wide, and 5 cm high) with a medium (buckwheat husk) to provide them with a living space as well as frozen moth eggs every two days. After placing moth eggs in the box, we gently shook the box to evenly distribute the eggs.

Predation experiment

In both no-choice and choice experiments involving minute pirate bugs and lacewings, adult minute pirate bugs and newly hatched first-instar lacewing larvae were used. The small cell for the predation experiment was adapted from the ones described in Wang *et al.* (2024). We first prepare two identical acrylic slides (30 mm long × 30 mm wide × 2 mm thick). The upper slide had a cylindrical hole (1 cm in diameter at both the top and bottom). The hole was covered with a piece of plastic wrap. Tweezers were used to poke a small hole in the plastic wrap. The small hole was then covered with another small piece of plastic wrap. An insect pin was then used to poke five small holes in the plastic wrap to ensure air circulation. A strawberry leaf (15 mm long x 15 mm wide) was placed below the cylindrical hole and was cushioned by four layers of filter paper to retain moisture. The lower slide did not have a cylindrical hole. Two metal clips were used to secure each cell assembly.

In the predator-prey experiment, top small pieces of plastic wrap were removed from the plastic wrap using tweezers. Prey and predators were then introduced into small cells through holes in the plastic wrap, and the small pieces of plastic wrap were then placed back over the holes. Finally, the experimental samples were placed in an incubator with the following conditions: temperature 25℃ ± 5℃, relative humidity 80%, and a photoperiod of 16 hours light: 8 hours dark. The number of prey consumed was counted at the end of each 24h test separately.

No-choice tests

Lacewings. For the adult western flower thrips test (replicate n=10), 1 first-instar lacewing larva plus 5 adult thrips were placed in each experimental cell. For the second-instar thrips test (replicate n=9): 1 first-instar lacewing larva plus 10 second-instar thrips nymphs were placed in each cell. For the first-instar thrips test (replicate n=9), 1 first-instar lacewing larva plus 10 first-instar thrips nymphs were placed in each cell.

Minute pirate bugs. For the adult western flower thrips test (replicate n=10), 1 adult pirate bug plus 5 adult thrips were placed in each experimental cell. For the second-instar thrips nymph no-choice test (replicate n=10), 1 adult pirate bug plus 10 second-instar thrips nymphs were placed in each cell. For the first-instar thrips nymph no-choice test (replicate n=8), 1 adult pirate bug plus 10 first-instar nymphs were placed in each cell.

Choice tests

Lacewings. For the choice test (replicate n=10), 1 first-instar lacewing larva, 5 adult thrips, 5 pupae, 5 second-instar nymphs plus 5 first-instar nymphs were placed in each cell in a mixture.

Minute pirate bugs. For the choice test (replicate n=9): 1 adult pirate bug, 5 adult thrips, 5 pupae, 5 second-instar nymphs plus 5 first-instar nymphs were placed in each cell.

Data analysis

The experimental data were analysed using R software version 4.51 (R Core Team 2024). The mean and standard error (SEM) of each treatment was calculated. The Shapiro-Wilk normality test showed that none of the data was normally distributed. Therefore, rank-variance analysis (ART) was used to compare the treatment effects and their interactions between predators and prey (Kay *et al.* 2021).

After assessing the overall predator × prey interaction, additional within-predator analyses were conducted. For each predator, an aligned rank transform (ART) one-way ANOVA was applied to assess differences in prey-stage susceptibility. Post hoc comparisons were performed using emmeans (Lenth 2024) with Tukey's correction, and statistically distinguishable prey-stage groups within each predator were distinguished.

In the choice test, we used *selectapref* package (Richardson 2020) to quantify prey-stage preference. We computed the Manly index (Manly 1974) for each predator in each replicate, based on the initial number of prey and the number of remaining prey after the experiment. This index accounts for the availability of prey and allows assessment of predator selectivity among different thrips stages.

For each predator in each replicate in the choice test, the Manly index was calculated using the following formula: $a_i = e_i / (e_1+e_2+e_3+e_4)$ where α_i represents the Manly index; e_1, e_2, e_3, and e_4 represent the number of first-instar nymph, second-instar nymph, pupa, and adult thrips predated. i denotes the ith prey type: i= 1 is first-instar nymph; i= 2 is second-instar nymph; i = 3 is pupal thrips; i = 4 is adult thrips. The Manly index of each thrips stage was analyzed by ART ANOVA for each predatory species for differences between prey stages within each species.

Results

No-choice test

Regardless of predatory species, significant differences were found in predation numbers on different thrip life stages ($F_{1, 50}$ = 70.68, $p < 0.005$)—the number of prey consumed was more when the prey was younger in life stage (Table 1). There were also significant differences in overall predation rates between the two predator species ($F_{2, 50}$ = 7.4277; p =0.009). However, the interaction between predator species and thrip life stage still had significant effect on predation number ($F_{2, 50}$ =5.7588; $p < 0.001$); and the difference between two predator species seemed most pronounced only when predators were feeding on the second-instar nymph thrips.

Choice test

There were significant differences among thrips stages attacked by the minute pirate bug ($F_{3, 32}$ = 7.9836, $p < 0.001$), and similarly significant differences consumed by the lacewing ($F_{3, 36}$ =26.998, $p < 0.0001$). In both cases, the highly mobile adults were least preferred (Table 2); lacewing larvae consumed more second instar thrips than adult minute pirate bugs ($F_{1, 17}$ = 14.203, $p < 0.01$).

Table 1. No-choice test, showing the mean ± standard error of the mean for the numbers of each stages of *Frankliniella occidentalis* consumed by first-instar lacewing larvae (*Mallada basalis*) and adult predatory bugs (*Buchananiella whitei*) over 24 hours; for thrips adults, predator-prey ratio was 1:5; for thrips nymphs, predator-prey ratio was 1:10. There were 10 replicates for each predator species. Means with the same superscript letter(s) within each line are not statistically different at $p < 0.05$.

Predators	**Life stage of prey**		
	Adult	**Nymph 2**	**Nymph 1**
Lacewing	3.8 ± 0.4^{a}	6.2 ± 1.0^{b}	9.7 ± 0.2^{c}
Predatory bug	3.3 ± 0.4^{a}	4.6 ± 0.4^{b}	10.0 ± 0.0^{c}

Table 2. Predation numbers (mean ± SEM) by first-instar lacewing larvae (*Mallada basalis*) and adult predatory bugs (*Buchananiella whitei*) preying on western flower thrips adults, pupae and nymphs (first and second instar) over 24 hours in a choice test. Within each row, means with different superscript letter(s) are statistically different at $p < 0.05$. Within each column, means with different numbers of stars are statistically different at $p < 0.05$.

Predator	**Life stages of prey (n = 5 individuals per stage)**				
	Adult	**Pupa**	**Second instar nymph**	**First instar nymph**	**No. replicates**
Lacewing	0.4 ± 0.2^{a}	3.4 ± 0.3^{b}	4.6 ± 0.2^{c} **	4.3 ± 0.3^{bc}	10
Minute pirate bug	0.4 ± 0.3^{a}	2.4 ± 0.4^{b}	2.7 ± 0.5^{b} *	3.8 ± 0.6^{b}	9

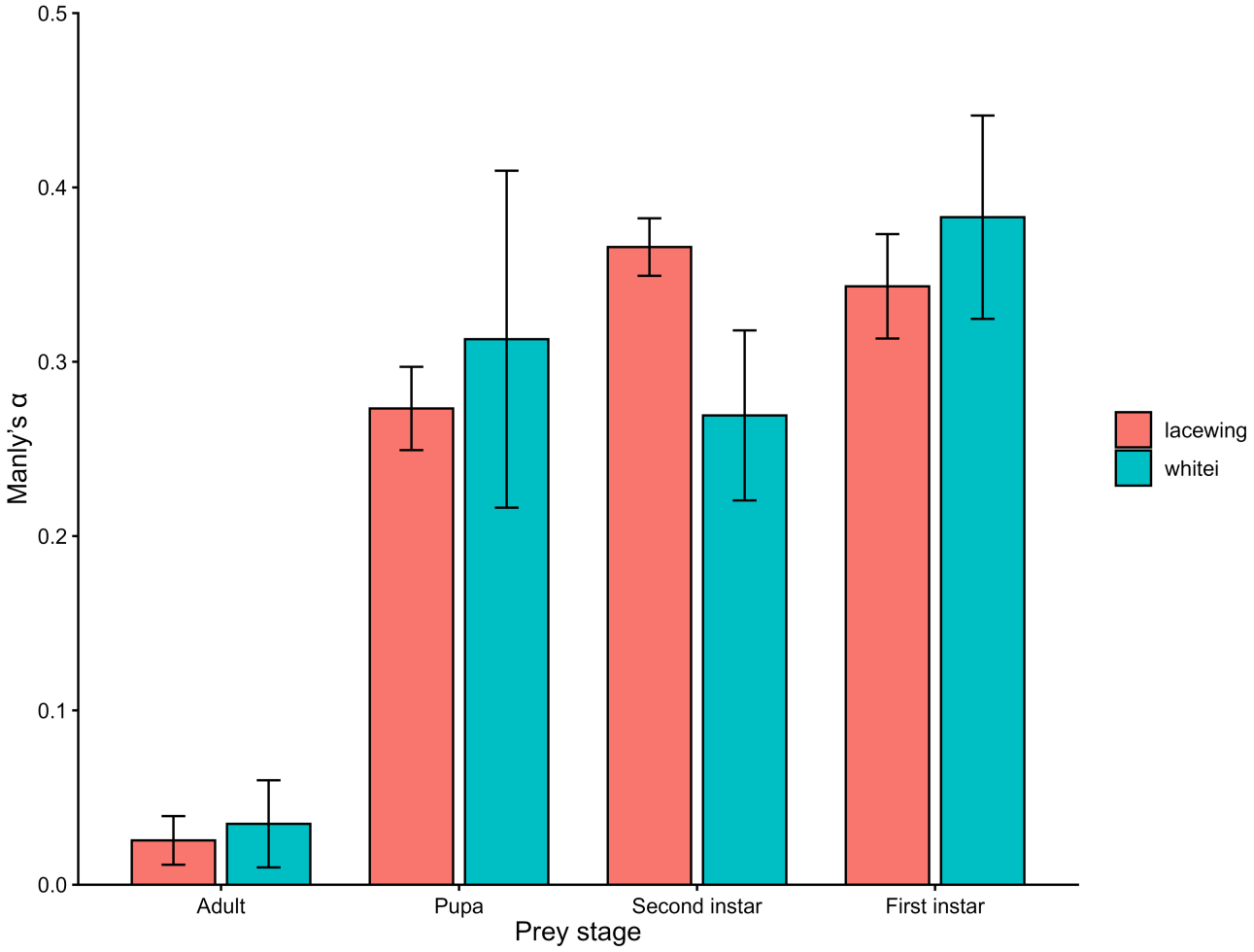

Figure 1. Manly index values (mean ± SEM) showing preferences for different life stages of western flower thrips when attacked by larval lacewings (*Mallada basalis*) and adult minute pirate bugs (*Buchananiella whitei)* in choice tests over 24 hours (5 prey individuals of each prey stage were mixed in each test).

Further analysis of prey stage preference using the Manly index showed that both predators preferred preying on the young nymph thrips (Fig. 1). For lacewings, there were highly different preferences between different thrips stages ($F_{3, 36} = 23.274$, $p < 0.001$), with adults much less preferred over first-instar nymphs ($t_{1,36} = -7.152$; $p<0.0001$), second

instar-nymphs ($t_{1,36}$ = –8.213 ; p < 0.0001), and pupae ($t_{1,36}$ = –4.546 ; p < 0.001); and pupae less preferred over second-instar nymphs ($t_{1,36}$ = –3.667; p < 0.05). The other pairwise comparisons showed no significant differences: pupae and first-instar thrips, first-instar thrips and second-instar thrips.

For minute pirate bugs, the Manly index also revealed highly different preferences between different thrips stages ($F_{3, 32}$=8.411, p < 0.001). Adult thrips were significantly less preferred than first-instar nymphs ($t_{1,32}$ =4.891; p < 0.001), second instar nymphs ($t_{1,32}$ =−3.284; p <0.05), or pupae ($t_{1,32}$ =−3.227; p <0.05).

Discussion

This study aimed to find out i) if the first instar larvae of *M. basalis* and adult *B. whitei* can feed on different stages of western flower thrips; ii) which thrips prey stage they prefer to eat. Our experiments showed that both *B. whitei* and *M. basalis* could eat immature and adult western flower thrips, and both consumed more young nymphs (especially first instar nymphs) than older stages (pupae and adults).

In the no-choice test, the two predatory insect species consumed more first-instar thrips than other life stages. In the choice test, the two predatory insect species also had a higher preference for first instar nymph thrips, indicating that they would be more likely to have better control over first-instar thrips than later life stages. Western flower thrips adults are highly mobile and can fly—this would also reduce their vulnerability to predation by lacewing larvae. However, the effectiveness of *B. whitei* and *M. basalis* as biological control agents against adults of *F. occidentalis* remains to be established by further studies, especially the potential effects of later instar larvae of *M. basalis* on thrips adults.

The mean number of western flower thrips adults consumed by another minute pirate bug—*Orius insidiosus* (Say, 1832)—per day in a study by Summerfield *et al.* (2024) was similar to the number preyed upon by *B. whitei* in this study. This shows that *B. whitei* is about as effective as *O. insidiosus* in attacking the adults of *F. occidentalis*. However, in other experiments (see Mouratidis *et al.* 2022), *Orius majusculus* (Reuter, 1879) and *O. laevigatus* (Fieber, 1860) showed better predation ability (*i.e.* higher prey mean numbers of prey consumed per day) on adult western flower thrips than *B. whitei*. The reason for the differences might be that Mouratidis *et al.* (2022) provided more prey adults in their tests (60 western flower thrips adults in one test, ours are 5 adults in one test), which increased the chances that *Orius* would encounter adult thrips.

In the no-choice test in this study, only 10 first-instar nymph thrips were provided: in all replicates, the lacewing larvae consumed all 10 prey items, which we inferred that these are lower than the upper limit of predation by first-instar lacewing larvae. If more prey were provided, first-instar lacewing larvae might consume more first-instar thrips nymphs. For example, in the experiment of Shrestha and Enkegaard (2013), the first-instar green lacewing, *Chrysopa pallens* (Rambur, 1838), could consume an average of 30 first-instar western flower thrips nymphs per day.

In our no-choice test and choice test, we observed that *B. whitei* adults laid eggs in some replicates, suggesting that thrips might sustain their reproduction. Further research could investigate whether *B. whitei* can complete its life cycle while preying solely on western flower thrips and perhaps demonstrate whether a *B. whitei* population can remain on strawberry plants by feeding on thrip populations for a longer period. Occasionally, we noted that *B. whitei* killed the western flower thrips but only partially consumed the prey—the thrip's corpse was relatively intact. This phenomenon might indicate that *B. whitei* could attack and kill more thrips than it needs to eat.

The main limitations of this study are that it did not distinguish between male and female minute pirate bugs, or standardize the starvation level of the bugs before conducting the predation tests, which might have affected the results. However, all treatments were similarly affected so we would expect relative results to be more or less the same. In addition, we did not conduct tests on the predation of western flower thrips by lacewing second and third instar larvae. Although our lacewings were sold as eggs which hatch to first-instar larvae when released, tests with only lacewing first-instar larvae cannot fully reflect the biological control potential of lacewings. In the no-choice test, we did not test the predation of pupa thrips by predators because there were insufficient pupa thrips in the culture at that time. Future experiments will examine the function response of predator species to prey density using more standardized cohorts of predators, as well as population predator-prey experiments in greenhouse or field plots to better understand the potential of these two predator species in controlling western flower thrips on strawberries.

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