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# Comparative studies of predation among feral, commercially-purchased, and laboratory-reared predators

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**Abstract** The predatory activities of commercially-purchased adult *Hippodamia convergens* Guérin-Méneville and two laboratory-reared strains of adult *Geocoris punctipes* (Say) were compared with their feral counterparts. In single prey choice feeding tests, commercially-purchased and feral *H. convergens* were provided copious amounts of silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring adults or eggs of pink bollworm, *Pectinophora gossypiella* (Saunders). Commercially-purchased *H. convergens* devoured more pink bollworm eggs and at a faster rate than the feral *H. convergens*. In contrast, feral *H. convergens* consumed more adult whiteflies and at a faster rate than commercial *H. convergens*. In multiple feeding choice tests, two distinctly different laboratory-reared strains and feral *G. punctipes* were provided a cotton leaf disk containing copious amounts of silverleaf whitefly eggs, nymphs, and adults. Virtually no predation was observed on whitefly eggs, but both laboratory strains of *G. punctipes* fed on more whitefly nymphs and adults than the feral *G. punctipes*. Moreover, both of the laboratory strains had a significantly faster feeding rate on adult whiteflies and spent significantly less time feeding on plant tissue than the feral strain. These results suggest that the augmentative biological control candidates retained their ability to prey on these selected prey items, even after being displaced from their overwintering site (*H. convergens*) or being reared in captivity (*G. punctipes*) for over 40 generations.

**Keywords** Predation · *Hippodamia convergens* · *Geocoris punctipes* · *Bemisia argentifolii* · *Pectinophora gossypiella* · Quality control · Augmentative/inundative biological control · Feeding behavior

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## Introduction

The use of broad spectrum insecticides continues to be the most common pest control tactic used throughout the world. However, with increasing concerns about groundwater contamination, pesticide residues in foods, insecticide resistance, secondary pest outbreaks, and the mounting cost of pesticides, growers are seeking more environmentally safe and cost-effective methods for controlling insect pests. One such method may include using natural enemies of insect pests that are released as part of an inundative (augmentative) biological control program. There are dozens of commercial producers worldwide that sell predators and parasitoids for inundative biological control (van Lenteren 2003). Unfortunately, the quality of most commercially available natural enemies has not been thoroughly evaluated. This is especially true for predaceous biological control agents. Despite the lack of predator efficacy data in the scientific literature, many producers of biological control agents are advertising them as "an environmental alternative to chemical control."

Many have suggested that biological control agents should be thoroughly tested for efficacy before they are sold to consumers (Hagler and Cohen 1991; Hoy et al. 1991; Parrella et al. 1992; Flint et al. 1995; O'Neil et al. 1998; Silvers et al. 2002; van Lenteren et al. 1997, 2003; Vasquez et al. 2004). Specifically, studies are needed to evaluate the fitness and efficacy of these predators (Roush 1990). If predators are improperly used or their effectiveness is misrepresented to the public, the biological control industry could suffer a loss of consumer confidence.

Here the results of two studies are provided that compared the predatory activity of commercially-purchased convergent lady beetles, *Hippodamia convergens* Guèrin-Mèneville (Coleoptera: Coccinellidae), and laboratory-reared big-eyed bugs, *Geocoris punctipes* (Say) (Hemiptera: Lygaeidae), with their feral counterparts. The first study examined the feeding behavior of feral and commercially-purchased *H. convergens* in single prey choice feeding arenas that contained either eggs of pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae) or adults of silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring (=*B. tabaci* [Genn.], strain B) (Hemiptera: Aleyrodidae). *H. convergens* was selected for this study because it is one of the most common predators sold to consumers for inundative biological control (van Lenteren 2003). Typically, the purchased beetles are mass-collected from their overwintering sites in the mountains of the northeastern United States and then sold to customers throughout the USA (Sherman 1938; Hagen 1962; Bennett and Lee 1989; Roach and Thomas 1991). This study was conducted to determine if the commercially-purchased beetles would feed like their feral counterparts on immobile pink bollworm eggs and mobile whitefly adults, prey items endemic to the arid southwestern United States. The second study compared the feeding behavior of feral and laboratory-reared *G. punctipes* in a multiple choice feeding arena that contained a cotton leaf disk infested with an abundance of whitefly eggs, nymphs, and adults. *G. punctipes* was selected for this study because it is one of the few predators that has potential for mass production on either host prey or artificial diet (Cohen 1985, 1992, 2000). Additionally, two separate laboratory-reared strains of *G. punctipes* were available for this investigation. The laboratory-reared *G. punctipes* were descendents of individuals continuously reared in captivity for approximately five years (>40 continuous generations) on a strict pink bollworm egg and green bean diet. The two laboratory-reared strains of *G. punctipes* differed in that one strain had "normal eye" color while the second strain consisted solely of individuals containing a visible mutant "red-eye" color. This study was conducted to determine if the laboratory-reared individuals would feed as readily on whiteflies as feral big-eyed bugs after being reared in captivity for so many generations.

## Materials and methods

### *Hippodamia convergens* single diet choice bioassay

#### *Test insects*

Feral *H. convergens* adults were collected at various times throughout the year from an alfalfa field located 25 km NW of Tucson, Arizona, USA. Commercial *H. convergens* were purchased on the same week that field collections were made from Nature's Control (Medford, Oregon, USA), a supplier of beneficial insects. Each cohort was placed in separate communal rearing containers containing only a wet sponge for water. Each group was held in separate containers for no more than three days prior to their bioassay.

#### *Single prey choice feeding arena*

The behaviors exhibited by individual feral and commercially-purchased beetles were observed in one of two feeding choice arenas. Before each individual observation, an adult beetle was placed in a Petri dish and starved, but provided with water ad libitum for 24 h. A single beetle was then placed into a 3.5 cm Petri dish containing either 40 three-day-old pink bollworm eggs or 40 three-day-old adult whiteflies. A total of 35 commercially-purchased and 41 feral beetles were observed feeding on pink bollworm eggs, and 24 commercially-purchased and 32 feral beetles were observed feeding on adult whiteflies. The behavior of each individual beetle was recorded continuously for 30 min. Preliminary observations of *H. convergens* behavior in the feeding arena revealed several distinct behaviors, therefore a behavioral ethogram (Lehner 1996) was used and its components were programmed into The Observer®, a software program designed specifically for animal behavior research (Noldus Information Systems, Ver. 3.0, Leesburg, Virginia, USA). Descriptions of the behaviors recorded are given in Table 1. A new feeding arena was constructed after each 30 min observation.

*Data analysis*

The number of each prey type consumed and the time spent feeding, walking, resting, probing, and grooming by feral and commercially-purchased beetles were recorded. Differences in the mean number of prey consumed in a 30 min period and in the amount of time spent in each behavioral event between the feral and commercially-purchased *H. convergens* were first analyzed by a Student's t-test. In most cases, these data did not fulfill the necessary assumptions of the t-test (e.g., both non-transformed and transformed data were not normally distributed and did not contain equal variances) (SigmaStat, Ver. 2.03, Chicago, Illinois, USA). In such cases, the non-parametric Mann-Whitney Rank Sum Test was used to identify significant differences between the two beetle treatments.

**Table 1** Description of the behavioral events recorded for feral and commercially-purchased *Hippodamia convergens* exposed to either pink bollworm eggs or whitefly adults in single prey choice feeding arenas

| Observed behavior | Description of the behavior |
|---|---|
| Walking | Lady beetle moving forward across the leaf surface |
| Resting | Lady beetle standing motionless |
| Grooming | Lady beetle making rapid movements with its fore or hind legs across its body surface and antennae |
| Orienting | Lady beetle pivoting on the leaf without advancing in any particular direction |
| Probing | Lady beetle probing a pink bollworm egg or a whitefly adult, but not feeding |
| Necrophagy | Lady beetle consuming a dead adult whitefly |
| Feeding | Lady beetle consuming a pink bollworm egg or a living adult whitefly |

*Geocoris punctipes* multiple diet choice bioassay

*Test insects*

Feral *G. punctipes* adults were collected 24 h prior to observation from a cotton field located at the University of Arizona's Maricopa Research Center, Maricopa, Arizona, USA. The collections were made at various times between the months of July and September. Upon return to the laboratory, the feral big-eyed bugs were placed individually in 9.0-cm Petri dishes containing a wet sponge. Two separate and very distinct laboratory colonies of *G. punctipes* were available for testing that were easily distinguishable by their eye color. The "normal-eyed" individuals were descendants of individuals collected approximately 5 years (>40 generations) prior to this study from an alfalfa field located near Maricopa, Arizona, USA. The "red-eyed" individuals were descendents from a laboratory colony reared at the University of Arkansas, USA since the late 1980s (the prior rearing history is unknown). Both groups of big-eyed bugs were fed pink bollworm eggs and green beans for five years prior to this study.

*Multiple prey choice feeding arena*

The behaviors of individual feral and laboratory reared big-eyed bug adults were recorded continuously for 30 min each in a multiple prey-choice feeding arena containing a cotton leaf disk infested with whitefly eggs, nymphs (various instars), and adults as described by Hagler et al. (2004). Briefly, cotton plants, *Gossypium hirsutum* L. (cv 'Delta Pine 5415') were grown in 15.2-cm diameter pots in a greenhouse using standard cultural practices. Four- to five-week-old plants were infested with adult whiteflies on a weekly basis. When the plants were $\approx$8–9 weeks old, a single cotton leaf containing numerous whitefly eggs and nymphs was removed from a plant and cut to fit exactly into the bottom of a 3.5-cm plastic Petri dish (the feeding arena). The number of whitefly eggs and nymphs were counted and the leaf was placed abaxial side up into the bottom of the feeding arena. Then, exactly 100 whitefly adults were introduced into the feeding arena and the Petri dish lid was placed over the top of the arena. A typical arena contained a 3.5-cm cotton leaf disk infested with 100 adult whiteflies (at a 1:1 sex ratio) and an average of 3,415 ± 243 and 1,570 ± 151 whitefly eggs and nymphs (various instars), respectively. A single big-eyed bug, held overnight without food, was then placed into the feeding arena and its behavior was continuously observed for 30 min under a dissecting microscope. A total of 30 individual big-eyed bugs were observed for each of the three *G. punctipes* treatment groups. Preliminary observations of *G. punctipes* behavior revealed several distinct behaviors, therefore a behavioral ethogram was used and its components were programmed in The Observer®. Descriptions of the big-eyed bugs behaviors recorded are given in Table 2. After each 30 min observation, the big-eyed bug was removed from the arena and replaced with another randomly selected big-eyed bug. No more than two predators were observed consecutively in the same arena. The feeding arenas were replaced daily with fresh plant and prey material.

### *Data analysis*

The mean number of prey consumed, the number of plant feeding events, and the mean durations of the feeding (on whitefly and plant tissue), walking, resting, probing (on whitefly and plant material), and grooming events among the three cohorts of *G. punctipes* were recorded. None of the data recorded conformed to the assumptions of normality and/or equal variances needed for a proper data analysis by ANOVA. Therefore, a Kruskal-Wallis one-way ANOVA on the ranked data was used to identify significant differences in the various behaviors among the three treatment groups (SigmaStat Ver. 2.03). When a significant difference was detected among the treatments, a Dunn's multiple comparison test was used to identify the statistically different means.

## Results

### *Hippodamia convergens* single diet choice bioassay containing pink bollworm eggs

The commercially-purchased beetles consumed significantly more eggs (Mann–Whitney Rank Sum Test, $T = 1{,}557$, $n[\text{commercial}] = 35$, $n[\text{feral}] = 41$, $P = 0.03$, Fig. 1a) and had a significantly faster feeding rate (prey handling time) than the feral beetles ($T = 223325$, $n[\text{commercial}] = 490$, $n[\text{feral}] = 525$, $P < 0.001$, Fig. 1b). On average, an individual commercially-purchased and feral beetle consumed 14.9 ± 2.0 and 13.8 ± 2.2 eggs every 30 min at a rate of

**Table 2** Description of the behavioral events recorded for feral and laboratory-reared *Geocoris punctipes* exposed to a cotton leaf disk containing the various whitefly lifestages in a prey- and plant-choice arena

| Observed behavior | Feeding choice on the various whitefly lifestages and cotton leaf disk | Description of the behavior |
|---|---|---|
| Walking | | Big-eyed bug moving forward across the leaf surface |
| Resting | | Big-eyed bug standing motionless |
| Grooming | | Big-eyed bug making rapid movements with its fore or hind legs across its body surface and antennae |
| Orienting | | Big-eyed bug pivoting on the leaf without advancing in any particular direction |
| Probing | Egg | Big-eyed bug probing a whitefly egg, but not feeding |
| | Nymph | Big-eyed bug probing a whitefly nymph, but not feeding |
| | Adult | Big-eyed bug probing a whitefly adult, but not feeding |
| Feeding | Egg | Big-eyed bug consuming an egg |
| | Nymph | Big-eyed bug consuming a nymph |
| | Adult | Big-eyed bug consuming an adult |
| | Plant | Big-eyed bug feeding on plant tissue |

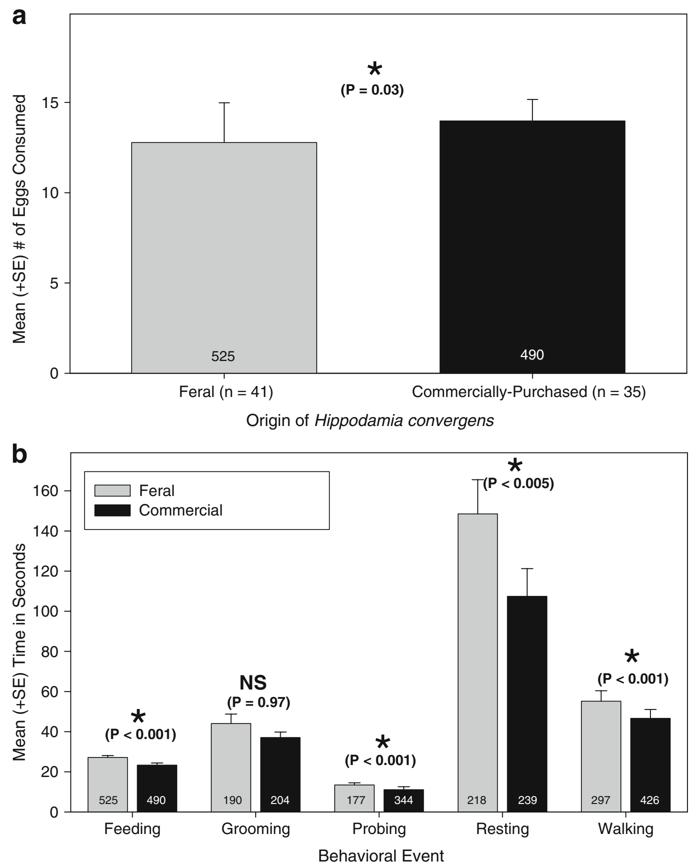


**Fig. 1** (**a**) Mean number of *Pectinophora gossypiella* eggs consumed by feral ($n = 41$, 30 min observations) and commercially-purchased ($n = 35$, 30 min observations) *Hippodamia convergens*. (**b**) Mean time of behavioral events recorded for feral and commercially-purchased *Hippodamia convergens*. The numbers inside the bars vertically adjacent to the x-axes are the total number of behavioral events recorded over the duration of the study. An asterisk or NS above each paired treatment indicates a significant or non-significant difference, respectively

23.4 ± 1.1 and 27.2 ± 0.9 s per egg, respectively (Fig. 1a, b). The mean time that the feral beetles spent probing ($T = 56{,}837$, $n$[commercial] = 344, $n$[feral] = 177, $P < 0.001$), resting ($T = 53{,}841$, $n$[commercial] = 239, $n$[feral] = 218, $P = 0.005$), and walking ($T = 117{,}445$, $n$[commercial] = 426, $n$[feral] = 297, $P < 0.001$) was significantly longer (Fig. 1b) and there was no difference ($T = 37560$, $n$[commercial] = 204, $n$[feral] = 190, $P < 0.97$) in the times that each beetle group spent grooming.

## *Hippodamia convergens* single diet choice bioassay containing adult whiteflies

The mean number of adult whiteflies consumed per individual beetle was significantly higher ($t = 3.18$, df = 54, $P = 0.003$, Fig. 2a), and the feeding time was significantly shorter ($T = 108{,}876$, $n$[commercial] = 222, $n$[feral] = 566, $P < 0.001$) for the feral beetles (Fig. 2b). On average, an individual feral and commercially-purchased beetle consumed 17.7 ± 1.9 and 9.1 ± 1.9 adult whiteflies every 30 min at a rate of 13.0 ± 0.3 and 20.4 ± 1.0 s per whitefly, respectively (Fig. 2a, b). The mean time spent probing ($T = 85{,}124$, $n$[commercial] = 266, $n$[feral] = 614, $P < 0.001$), resting ($T = 45{,}996$, $n$[commercial] = 371, $n$[feral] = 153, $P < 0.001$), and grooming ($T = 33{,}530$, $n$[commercial] = 184, $n$[feral] = 273, $P < 0.001$) by the feral beetles was significantly longer than that of their commercially-purchased counterparts (Fig. 2b). There was no significant difference in the amount of time the two groups of beetles spent walking ($T = 406{,}061$, $n$[commercial] = 729, $n$[feral] = 605, $P = 0.751$) and feeding ($T = 340$, $n$[commercial] = 17, $n$[feral] = 19, $P = 0.438$) on dead whiteflies (necrophagy).

## *Geocoris punctipes* multiple diet choice bioassay containing the various whitefly lifestages

The *G. punctipes* were reticent to feed on whitefly eggs with only four whitefly eggs consumed over the duration of the study, all by the red-eyed mutant strain (Fig. 3a). There were no significant differences

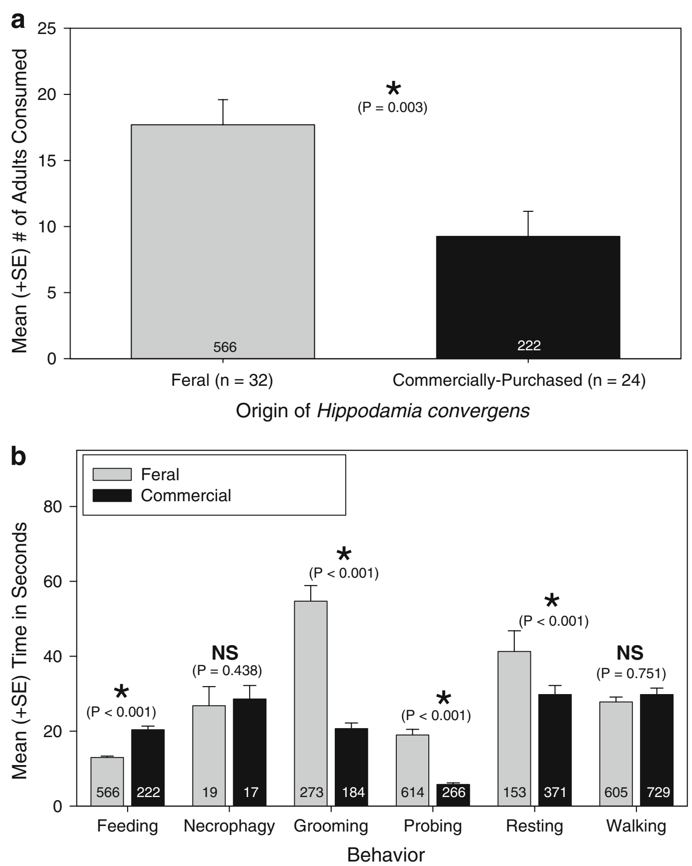


**Fig. 2** (**a**) Mean number of *Bemisia argentifolii* adults consumed by feral ($n = 32$, 30 min observations) and commercially-purchased ($n = 24$, 30 min observations) *Hippodamia convergens*. (**b**) Mean time of behavioral events recorded for feral and commercially-purchased *Hippodamia convergens*. The numbers inside the bars are the number of recorded observations for each behavioral event. An asterisk or NS above each paired treatment indicates a significant or non-significant difference, respectively

in the mean number of whitefly nymphs consumed per individual ($H = 2.8$, df = 2, $P = 0.249$) among the three treatment groups (Fig. 3a). However, the normal-eyed and red-eyed strains consumed two to three times more adult whiteflies than the feral strain ($H = 20.5$, df = 2, $P < 0.001$; Fig. 3a). The mean feeding duration on whitefly nymphs was not significantly different among the three treatment groups ($H = 2.7$, df = 2, $P = 0.248$; Fig. 3b). However, the feral strain had a significantly longer prey handling time on adult whiteflies ($H = 22.161$, df = 2, $P < 0.001$) (Fig. 3b). The non-feeding behaviors exhibited by each cohort of *G. punctipes* revealed that the red-eyed *G. punctipes* spent significantly less time grooming ($H = 12.413$, df = 2 $P = 0.002$), resting ($H = 27.023$, df = 2, $P < 0.001$), and walking ($H = 24.561$, df = 2, $P < 0.001$) than the feral and normal-eyed *G. punctipes* (Fig. 3c). The mean duration of orienting was not significantly different between the three strains ($H = 2.594$, df = 2, $P = 0.237$).

The occurrence of probing was rare on whitefly nymphs and adults and almost nonexistent on eggs for the feral and normal-eyed *G. punctipes* (Fig. 3d). However, the red-eyed strain was frequently observed probing ($n = 60$ probing events) whitefly eggs. The duration of probing events on whitefly nymphs ($H = 5.041$, df = 2, $P = 0.080$) and adults ($H = 1.329$, df = 2, $P = 0.515$) was not significantly different among the three groups of big-eyed bugs (Fig. 3d).

The number of plant feeding events exhibited by the three cohorts of *G. punctipes* were not significantly different with an average of less than two feeding events occurring every 30 min ($H = 5.952$, df = 2, $P = 0.051$; Fig. 4a). However, the duration of plant feeding events was significantly different among all three treatment groups with feral > normal-eyed > red-eyed, respectively ($H = 28.032$, df = 2, $P < 0.001$; Fig. 4b). Also, the mean duration of plant probing events was approximately 2.5 times longer for the feral *G. punctipes* than the normal-eyed

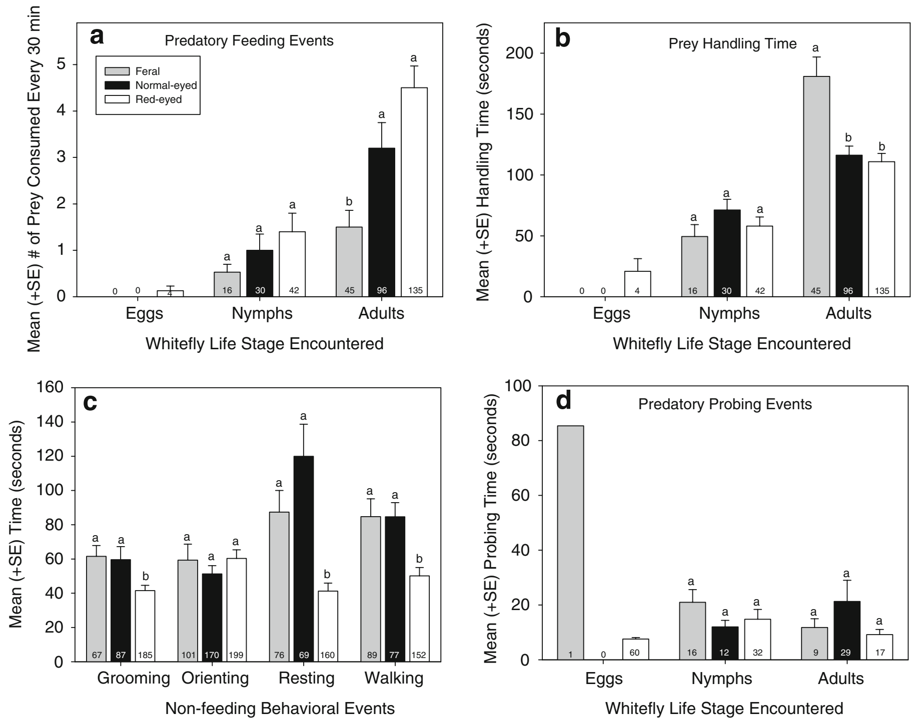


**Fig. 3** (**a**) Mean number of *Bemisia argentifolii* eggs, nymphs, and adults consumed by feral, normal-eyed, and red-eyed ($n = 30$, 30 min observations for each treatment group) *Geocoris punctipes*. (**b**) Mean prey handling time of feral, normal-eyed, and red-eyed *G. punctipes* on *B. argentifolii* eggs, nymphs, and adults. (**c**) Mean time of behavioral events recorded for feral, normal-eyed, and red-eyed *G. punctipes*. (**d**) Mean probing time of feral, normal-eyed, and red-eyed *G. punctipes* on *B. argentifolii* eggs, nymphs, and adults. The numbers inside the bars vertically adjacent to the x-axes are the total number of behavioral events recorded over the duration of the study. Bars followed by the same letter are not significantly different

and red-eyed strains ($H = 14.631$, df $= 2$, $P < 0.001$; Fig. 4c).

## Discussion

An ideal entomophage should feed rapidly and frequently on its targeted prey (Cohen 2000; De Clercq 2002). A major concern of the biological control industry is that commercially-purchased predators, whether they are mass-produced on artificial diet or mass-collected from the field, may not feed as readily on targeted prey items as their feral counterparts. In the first part of this study, the feeding activity of commercially-purchased *H. convergens* was compared with their feral counterparts endemic to the southwestern desert in the USA. The purpose of this study was to determine if the purchased beetles which were collected from their cool overwintering sites in Oregon (Sherman 1938; Hagen 1962; Bennett and Lee 1989; Roach and Thomas 1991), shipped to Arizona, and stored for several days in a refrigerator would feed as readily as their feral counterparts on prey items endemic to the arid southwestern USA (e.g., pink bollworm eggs and adult whiteflies). Results reported here revealed that the commercially-purchased *H. convergens* adults were significantly better predators than feral beetles on pink bollworm eggs, but not on adult whiteflies in single diet choice arenas. The laboratory results obtained for beetles feeding on whitefly were in sharp contrast to research results yielded from a field study designed to assess the feeding behavior of mass-released *H. convergens*. In that study, a molecular gut content analysis revealed that a higher proportion of mass-released beetles contained whitefly remains in their gut than the feral beetles (Hagler and Naranjo 2004). In short, it appears that commercially-

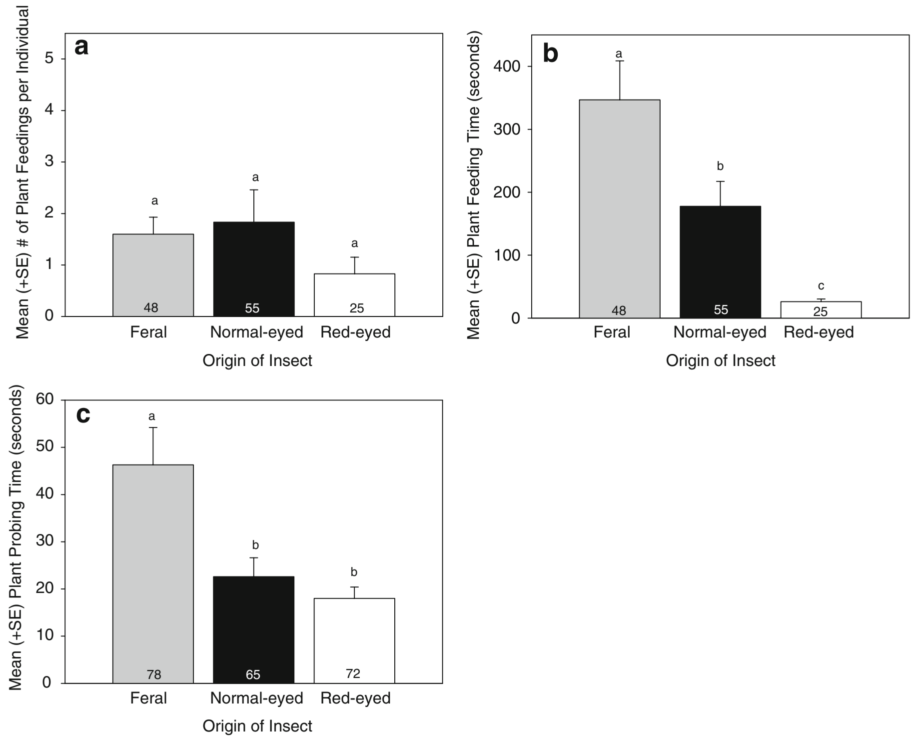


**Fig. 4** (**a**) Mean numbers of plant feeding events exhibited by feral, normal-eyed, and red-eyed ($n = 30$, 30 min observations for each treatment group) *Geocoris punctipes*. (**b**) Mean plant feeding duration of feral, normal-eyed, and red-eyed *G. punctipes* on the cotton leaf tissue. (**c**) Mean plant probing time of feral, normal-eyed, and red-eyed *G. punctipes* on the cotton leaf tissue. The numbers inside the bars vertically adjacent to the x-axes are the total number of behavioral events recorded over the duration of the study. Bars followed by the same letter are not significantly different

purchased beetles retained their ability to prey on pink bollworm eggs and at varying levels on whiteflies without any preconditioning to the targeted prey or environment.

This study indicates that commercially-purchased adult *H. convergens* retain their innate ability to feed on selected prey. However, there are still certain limitations that restrict their efficacy as inundative biological control agents in open-field situations. Previously, their poor performance has been attributed mainly to the fact that they do not remain long at their target site because of their tendency to disperse (Hagen 1962; Kieckhefer and Olsen 1974; Rankin and Rankin 1980; Davis and Kirkland 1982; Flint et al. 1995; Driestadt and Flint 1996; Obrycki and Kring 1998). For example, Hagler and Naranjo (2004) showed that only 3,642 of the ≈540,000 marked adult *H. convergens* released (≈0.7%) were recaptured. Of these, 2,427, 883, and 332 were recaptured 3, 8, and 15 days after release, respectively. The steady decline in recovery rates of marked beetles with each subsequent sampling date after release support the findings of other studies showing that *H. convergens* typically leave their release sites or die within days after release (Kieckhefer and Olsen 1974; Davis and Kirkland 1982; Driestadt and Flint 1996). This study and others (Hagler and Naranjo 2004) show that commercially-purchased adult beetles will likely prey on targeted pests, but methods (e.g., perhaps mechanical or cultural) are needed to entice the very mobile adult life stage to remain at their point of release in order for effective biological control to be achieved. For example, a flightless laboratory strain of *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae) has been identified as a potential biological control candidate for aphids (Tourniaire et al. 2000). Perhaps a flightless, less mobile strain of *H. convergens* could be selected for and then mass-produced. Flightless *H. convergens* could provide much more effective control of targeted pest species.

The two cohorts of *G. punctipes* that were reared continuously in the laboratory on only pink bollworm eggs and green beans for over five years (>40 continuous generations) offered a unique opportunity to study their feeding behavior with their desert-adapted (feral) counterparts. The study was conducted to determine if the laboratory reared strains would lose their innate ability to feed on alternate prey items after being conditioned to feed on pink bollworm eggs and green beans for so long. The results revealed that both groups of laboratory-reared bugs fed significantly more on adults and had significantly shorter handling times than their feral counterparts. These data support previous research that showed that *G. punctipes* reared for 60 continuous generations on a meat-based artificial diet can resume "normal" predation on a wide variety of prey types (Hagler and Cohen 1991; Cohen 2000). Moreover, both groups of laboratory reared big-eyed bugs spent less time feeding on cotton leaf tissue.

An interesting aspect of the current study was that two distinctive laboratory strains of *G. punctipes* were tested. The original colony consisted of individuals that had "normal eyes" and the second colony had individuals that had "red eyes." Insect eye color mutations have been reported for a wide variety of insects including *P. gossypiella* (Bartlett and Lewis 1978), *Drosophila melanogaster* Meigen (Lindsley and Grell 1968), *Ceratitis capitata* (Wiedemann) (Saul 1982), *Dacus dorsalis* Hendel (McCombs and Saul 1989), *Anastrepha fraterculus* (Wiedemann) (Yamada and Selivon 2001), and *Lygus lineolaris* (Palisot de Beauvois) (Snodgrass 2002). Snodgrass (2002) determined that there were no significant differences in egg production and egg viability between a normal-eyed and a red-eyed mutant strain of *L. lineolaris* that was reared continuously in the laboratory for over five years (>40 generations). Results from this study showed that red-eyed *G. punctipes* were more voracious whitefly predators and less likely to feed on plant material than both the feral and normal-eyed *G. punctipes*. These results suggest that both strains of laboratory-reared *G. punctipes* merit further testing under field conditions. In the future, we plan to release laboratory-reared *G. punctipes* in the field and then compare their feeding profiles with feral bugs via molecular gut content analyses (Hagler and Naranjo 1996, 2004). The red-eye strain of *G. punctipes* will be perfectly suited for such a study because the red eye mutation can be used to differentiate the released predators from their feral counterparts (Hagler and Jackson 2001).

This study shows that both commercially-purchased lady beetles and laboratory-reared big-eyed bugs retain their ability of feed on selected prey items. However, it is emphasized that laboratory tests such as this one are just the first step toward evaluating predaceous biological control agents. There are several drawbacks associated with studies conducted in confined laboratory arenas which could lead to erroneous estimates of predation. First, the prey population in each arena was higher than the predators would encounter in nature. Second, the enclosed arenas eliminate the ability of mobile prey to escape predation. Finally, these generalist predators were not provided with any alternate prey choices. In short, the results yielded from this study are only the first step toward assessing predation. The encouraging results suggest that more complex studies are warranted to further validate the efficacy of these predators in greenhouse or open field situations.

In summary, although dozens of companies sell arthropod predators for use as augmentative biological control agents, relatively little effort has been devoted to the critical assessment of the biological control candidates (O'Neil et al. 1998). Moreover, as mass rearing technology improves, there will likely be more predators produced on artificial diets via large-scale automated systems (Cohen 1985, 2000; De Clercq and Degheele 1993; De Clercq et al. 1998a; Grundy et al. 2000; Rojas et al. 2000; Reeve et al. 2003; van Lenteren 2003; Grenier and De Clercq 2003). Determining if mass-produced predators feed satisfactorily on targeted pests and in comparison to feral insects is of paramount importance for the development of a viable and trustworthy quality assessments which are needed for inundative biological control programs. Clearly vigorous testing standards are needed to determine if predators might become domesticated or lack the conditioning necessary to hunt, capture, and feed on prey items under field conditions (Hagler and Cohen 1991; Hagler and Naranjo 2004). Laboratory studies like the one presented here along with thorough field studies of predation and dispersal (Hagler and Naranjo 2004) are just two types of studies needed to validate the use of augmentative biological control agents for pest control. Additionally, further quality control standards are needed to precisely assess predator fitness rearing conditions (De Clercq et al. 1998b; Cohen 2000), and shipping conditions (O'Neil et al. 1998) to assure viable biological control agents.

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