Predation capability of Hippodamia convergens (Coleoptera: Coccinellidae) and Chrysoperla carnea (Neuroptera: Chrysopidae) feeding of Melanaphis sacchari (Hemiptera: Aphididae)

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Source: Florida Entomologist, 102(1) : 24-28

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.102.0104

Predation capability of *Hippodamia convergens* (Coleoptera: Coccinellidae) and *Chrysoperla carnea* (Neuroptera: Chrysopidae) feeding of *Melanaphis sacchari* (Hemiptera: Aphididae)

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Abstract

The sugarcane aphid, *Melanaphis sacchari* (Zehntner) Hemiptera: Aphididae), was first detected in Mexico in 2013. Since then, it has caused significant yield losses in sorghum, *Sorghum bicolor* (L.) Moench (Poaceae). The objective of this work was to evaluate, under laboratory conditions, the predation capability for the sugarcane aphid, measured as the consumption rate, of 2 predator species commonly used as biocontrol agents for different aphid species. We evaluated the consumption rate of larvae and adults of the convergent ladybeetle, *Hippodamia convergens* (Guérin-Méneville) (Coleoptera: Coccinellidae) when exposed to 100 aphid specimens for either 30 or 60 min. A second experiment compared the consumption rate of males and females of *H. convergens* exposed to different densities (4, 8, 16, 32, 64, and 128) of aphids in a 24-h period. We also tested the consumption rate of larvae of the common green lacewing, *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), in a 24-h period at different aphid densities (8, 16, 32, and 64). Larvae of *H. convergens* had a statistically significant higher consumption rate for the 30-min session compared to adults. However, for the 60-min session, the consumption rate was similar for both. The consumption rate between males and females at different aphid densities did not show statistical differences, except for the 64-aphid density; females consumed 85.9% of the aphids, compared to 68.2% by the males. Finally, a positive correlation was observed between prey density and prey consumption of *C. carnea* larvae. The regression model showed that they could consume an average of 15 aphids per d.

Key Words: sorghum; sugarcane aphid; convergent ladybeetle; common green lacewing; natural enemy; biological control

Resumen

El pulgón amarillo, *Melanaphis sacchari* Zehntner, 1897 (Hemiptera: Aphididae) fue detectado por primera vez en México en 2013. Desde entonces ha causado pérdidas significativas en sorgo, *Sorghum bicolor* (L.) Moench (Poaceae). El objetivo principal de este trabajo fue evaluar la capacidad de consumo del pulgón amarillo de dos especies depredadoras utilizadas comúnmente como agentes de control biológico, en condiciones de laboratorio. La tasa de consumo de larvas y adultos de la catarinita convergente *Hippodamia convergens* Guérin-Méneville, 1842 (Coleoptera: Coccinellidae) fue evaluada al exponer 100 pulgones amarillos por un período de 30 o 60 min. Un segundo experimento comparó la tasa de consumo de hembras y machos de la catarinita convergente, *H. convergens* bajo diferentes densidades de presa (4, 8, 16, 32, 64, y 128 pulgones amarillos) en un periodo de 24 h. La tasa de consumo de la crisopa *Chrysoperla carnea* Stephens, 1836 (Neuroptera: Chrysopidae), fue evaluada en un periodo de 24 h bajo diferentes densidades de presa (8, 16, 32, y 64 pulgones amarillos). La tasa de consumo en un periodo de 30 min fue estadísticamente más grande para las larvas de *H. convergens* que la de adultos. Sin embargo, la tasa de consumo del periodo de 60 min fue similar para las larvas y los adultos. La tasa de consumo también fue similar ente hembras y machos expuestos a diferentes densidades de presa, a excepción de la densidad de 64 pulgones amarillos. A esta densidad de presa, las hembras consumieron 85.9% de los pulgones, comparado con solo 68.2% por los machos. Finalmente, las larvas de *C. carnea* mostraron una correlación positiva ente la densidad de la presa y la tasa de consumo. El modelo de regresión mostró que las larvas pueden consumir en promedio 15 pulgones amarillos por día.

Palabras Clave: sorgo; pulgón amarillo; catarinita convergente; crisopa; enemigo natural; control biológico

In Mexico, about 1,500,000 ha of sorghum, *Sorghum bicolor* (L.) Moench (Poaceae), is grown each year, mainly in the states of Tamaulipas, Guanajuato, Sinaloa, y Michoacán (SIAP 2017). Several insects of economic importance are associated with sorghum in Mexico. However, since 2013 the sugarcane aphid, *Melanaphis sacchari* (Zehntner) (Hemiptera: Aphididae), has become the most important pest for this crop in the state of Guanajuato (SENASICA 2014), causing crop losses of up to 100% (López-Gutiérrez et al. 2016).

More than 47 species of natural enemies of the sugarcane aphid have been identified worldwide (Singh et al. 2004). So far in Mexico, 29 species of natural enemies have been documented belonging to the families Coccinellidae, Chrysopidae, Syrphidae, and Aphidiidae

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(INIFAP 2015; Cortez-Mondaca et al. 2016; López-Gutiérrez et al. 2016; Rodríguez-Palomera et al. 2016; Vázquez-Navarro et al. 2016).

Two of the most common predators of aphids are the convergent ladybeetle, *Hippodamia convergens* (Guérin-Méneville) (Coleoptera: Coccinellidae), and the common green lacewing, *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) (Martínez-Jaime et al. 2014; Salas-Araiza et al. 2015b). Both the larvae and adult forms of the convergent ladybeetle are strictly aphidophagous (Diehl et al. 2013). In contrast, the larval stage of *C. carnea* is considered a generalist carnivore. They usually feed on insects such as whiteflies and different species of mites (López-Arrollo et al. 2008), but also are known to be voracious aphidophages (Shelton 1993), particularly the last larval instar that has the greatest prey consumption rate (Salas-Araiza et al. 2015a).

The presence of the sugarcane aphid in the state of Guanajuato has caused a crisis in sorghum production. In order to develop techniques for the control of this new pest, it is important to contribute to the knowledge of potential natural enemies that are native to the agroecosystems in the state of Guanajuato. The objective of this study was to evaluate the consumption rate and efficacy of *H. convergens* and *C. carnea* as biocontrol agents for *M. sacchari*.

Materials and Methods

All experiments were carried out in the laboratory of Entomology of the Agronomy Department of the University of Guanajuato. Specimens of *M. sacchari* and *H. convergens* (see below) were collected from 12 Aug to 13 Sep 2015 in a field planted with sorghum (var. Pioneer 82G93) located in the experimental field of the university (20.44392°N, 101.19394°W; 1,728 masl).

Specimens of the sugarcane aphid were collected daily from the field by cutting infested sorghum leaves. The collected aphids were used to feed the natural enemies during the experiments.

To obtain larvae of *H. convergens*, 6 adult females were collected from the field during mating. They were placed in Petri dishes and fed with *M. sacchari* nymphs ad libitum until they oviposited. The eggs were kept in Petri dishes until hatching, between 25 to 28 °C, 60 to 65% RH, and 16:8 h (L:D) photoperiod. The larvae were introduced to the experiments 24 h after hatching and were not fed prior to that point.

Adults of *H. convergens*, both male and female, were captured in the field and used to evaluate the consumption rate when feeding on the sugarcane aphid. The specimens were sexed and kept in entomological cages, provided only with water, and kept between 25 to 28 °C and 60 to 65% RH until used for the experiments. Before starting the experiments, the adults were kept on a 12-h fast.

The Laboratory of Beneficial Insects of the University of Guanajuato provided the larvae of *C. carnea*. The larvae were reared in an artificial breeding program under controlled conditions, and fed with eggs of *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae).

The experimental unit for each of the experiments consisted of a Petri dish (9 × 1.5 cm) with a 3 × 7 cm piece of sorghum leaf, and a small piece of water-soaked cotton. The number of sugarcane aphids varied, depending on the treatment (see below). Three experiments were conducted to evaluate the consumption rate (see below).

CONSUMPTION RATE OF FEMALE AND MALE ADULTS OF *HIPPODAMIA CONVERGENS*

The consumption rate of females and males over a 24-h period was estimated using 6 different aphid densities (4, 8, 16, 32, 64, and 128 aphids). The aphids used in the experiment were of various nymphal stages, and no adults were included. For each treatment, 1 adult *H. convergens* was placed on an individual 9 × 1.5 cm Petri dish. There were 3 replicates per treatment. During the experiment, the insects were kept between 25 to 28 °C, 65% RH, and 16:8 h (L:D) photoperiod. The number of surviving aphids at the end of the trial was recorded to obtain the percent consumption. The data was analyzed via 2-sample *t*-test comparing the means of 2 independent groups, using Statgraphics Plus Ver. 5.1 Professional 2001 (STSC and Statistical Graphics Corporation, Bakersville, Maryland, USA).

CONSUMPTION RATE OF LARVAE AND ADULTS OF *HIPPODAMIA CONVERGENS*

The consumption rate of 100 sugarcane aphids of mixed nymphal stages was compared between larvae and adults of *H. convergens* at 2 different times of exposure to prey (30 and 60 min). Both larvae and adults of *H. convergens* were placed in individual Petri dishes. For this test, the sex of the adults was disregarded. There were 4 replicates of each treatment. The data was analyzed via independent 2-sample *t*-test.

CONSUMPTION RATE OF LARVAE OF *CHRYSOPERLIA CARNEA*

The consumption rate of larvae of *C. carnea* was estimated using 5 different aphid densities (4, 8, 16, 32, and 64) of mixed nymphal stages, over a 5-d period. One individual larva of the first instar was placed on a Petri dish with the specified aphid density. The plate was left for a period of 24 h, after which the surviving aphids were counted and removed, and a new cohort of sugarcane aphids introduced. By the end of the experiment, the larvae of *C. carnea* had reached the fourth instar. The experiment was repeated 5 times.

The data were adjusted using a simple linear regression model, using the least squares estimation method. The average percentage of aphids consumed daily was the dependent variable, and the exposure time (in days) for each aphid density was the independent variable. The goodness of fit of the model was evaluated using the coefficient of determination.

Results

CONSUMPTION RATE OF FEMALE AND MALE ADULTS OF *HIPPODAMIA CONVERGENS*

After a 24 h period of exposure to different aphid densities, there were no statistically significant differences in the consumption rate (in %) of *M. sacchari* when comparing male and female adults of *H. convergens*. The only exception was at a density of 64 aphids (t = 3.625; P = 0.0222), where females consumed 85.9 ± 7.7% of the aphids compared to 68.2 ± 19.5% of aphid consumption by the males (Fig. 1).

CONSUMPTION RATE OF LARVAE AND ADULTS OF *HIPPODAMIA CONVERGENS*

There was a statistically significant difference between the consumption rate of larvae and adults of *H. convergens* when allowed to freely forage 100 aphids for 30 min (t = −2.99; P = 0.0400). The larvae of *H. convergens* showed a higher consumption rate than adults, 87.6 ± 53.1% compared to 45.6 ± 28.6% of consumed aphids, respectively

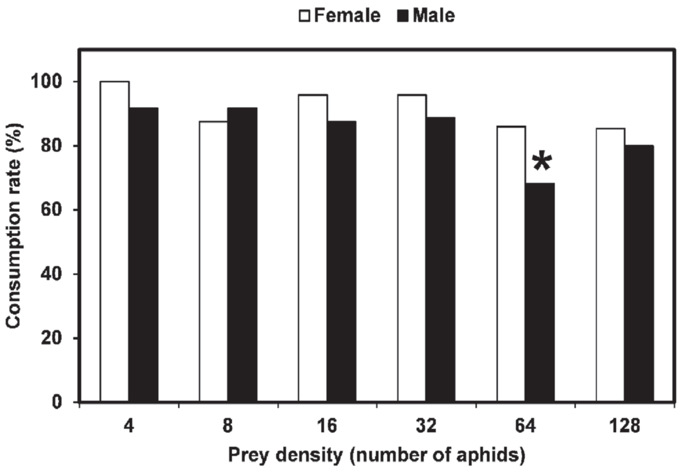

Fig. 1. Average consumption rate by adult males and females of the convergent ladybeetle (*Hippodamia convergens*) when allowed to freely forage for 24 h at different prey densities (4, 8, 16, 32, 64, or 128 aphids). The only statistical difference was found at density of 64 aphids (t = 3.625; P = 0.0222).

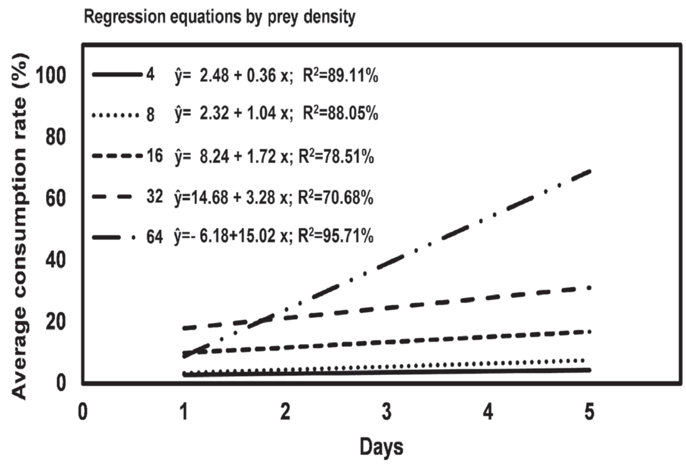

Fig. 3. Fitted linear regression models and their respective coefficient of determination (R^2) for the daily prey-consumption rate (%) of larvae of *Chrysoperla carnea* at 5 aphid densities over a period of 5 d.

(Fig. 2). In comparison, there was not a statistically significant difference (t = −0.2991; P = 0.7692) in the consumption rate between larvae (72.5 ± 22.7%) and adults (68.6 ± 20.5%) of the convergent ladybeetle after 60 min of exposure to the aphids.

CONSUMPTION RATE OF LARVAE OF *CHRYSOPERLIA CARNEA*

The best-fitted models were linear (Fig. 3), with a general equation of = a + bx where is the average daily consumption rate (%) of aphids, x is the time allowed for foraging, b (the slope of the curve) represents the average increase of consumption rate for each d that passes, and a is a constant representing the initial number of aphids consumed on d 1. There was a statistically significant difference between the slopes of the 5 models ($F_{4,9}$ = 16.6; P-value < 0.001), with the density of 64 aphids being different from the others (Fig. 3).

There was a positive correlation between prey availability and prey consumption rate for the larvae of *C. carnea* (Fig. 3). However, as the best model fit was linear, we were not able to determine the maximal prey consumption rate (inflection point), after which the consumption rate would diminish, nor if this would be affected by the amount of available prey and time (after d 5).

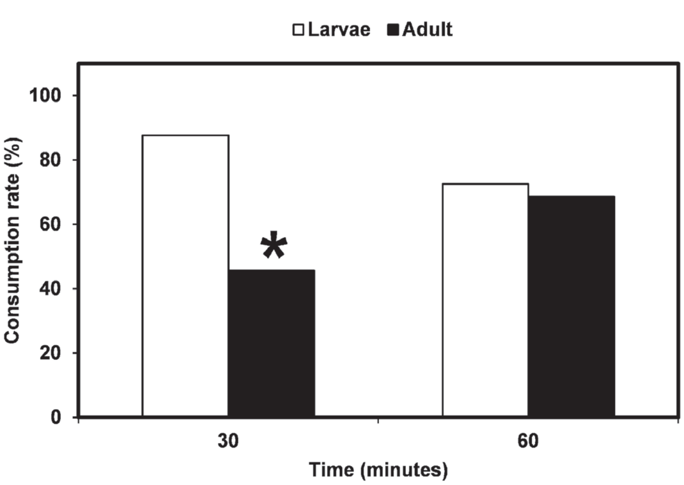

Fig. 2. Average of consumption rate (in %) of aphids by larvae and adults of *Hippodamia convergens* when allowed to freely forage 100 aphids for a period of 30 or 60 min. Larvae had a higher consumption rate, compared to adults, only for the 30-min period (t = −2.99; P = 0.0400).

Discussion

The arrival of the sugarcane aphid *M. sacchari* to Mexico has caused a significant disruption of sorghum production in the country, and it has quickly become the principal pest for this crop, causing up to 100% crop losses in the state of Guanajuato (SENASICA 2014; López-Gutiérrez et al. 2016). It is of the utmost importance to evaluate the biocontrol potential of natural enemies of the sugarcane aphid that are present naturally in Mexico. We evaluated the consumption rate of 2 aphidophagous species of the sugarcane aphid in sorghum: the convergent ladybeetle, *Hippodamia convergens*, and the common green lacewing, *Chrysoperla carnea*.

The consumption rate of females and males of *H. convergens* were similar, except at a density of 64 aphids, where females consumed more aphids than males. Females generally have been shown to have a higher consumption rate, which could be attributed to a higher metabolic requirement during mating and oviposition (Mallama-Goyes & Eraso-Gómez 2015). For example, Sanzón-Gómez (1998) observed that females consumed 34.4 aphids per d of a mix of *Metolophium dirhodum* (Walker), *Schizaphis graminum* (Rondani), *Sitobium avenae* (F.), and *Rhopalosiphum padi* (L.) (all Hemiptera: Aphididae), whereas the males consumed only 23, a consumption rate significantly lower than in our study.

Similarly, for the density treatment of 128 aphids, both males and females of *H. convergens* consumed more sugarcane aphids than values previously reported for 11 different aphid species (Sandoval-Sotomayor 1973). In another study, Elliot et al. (2000) reported that the foraging and preying capacity of *H. convergens* is tightly correlated with the population density of the aphid colony and the temperature. Tenorio-Vallejo et al. (1992) reported that males of *H. convergens* consumed 9 adult individuals per d of the pea aphid *Acyrtosiphum pisum* (Harris) (Hemiptera: Aphididae), whereas the females consumed 10.1 adult aphids. In comparison, our results showed that on average, adult females and males of *H. convergens* consumed an average of 55 and 43 sugarcane aphids of mixed instars, respectively, in a 24-h period. The difference in the consumption rate between the 2 aphid species (sugarcane aphid and pea aphid) could be due to the differences in their size.

Adult aphids of the pea aphid (*A. pisum*) measure between 4.0 to 4.5 mm in length. In contrast, nymphs and adults of the sugarcane aphid (*M. sacchari*) measure on average between 1.1 to 2.0 mm in length.

Regarding the consumption rate of the larvae of *H. convergens*, previous work has shown a positive correlation between the developmental stages of carnivorous larvae and the amount of prey consumed. In our study, we did not evaluate the consumption rate of *H. convergens* by larval instar. However, our results showed that the fourth larval instar consumed a greater number of prey than did the adult stage, and these results agree with the ones reported by Sandoval-Sotomayor (1973), Tenorio-Vallejo et al. (1992), Juvera-Bracamontes et al. (1995), Sanzón-Gómez (1998), Loera-Gallardo and Kokubu (2001), Figueira et al. (2003), and Mallama-Goyes and Eraso-Gómez (2015). The increase in the consumption of prey by the last larval instar could possibly be due to the need to store reserves for the adult stage; it has been observed that if the populations of *M. sacchari* are not sufficiently abundant, populations of *H. convergens* remain in reproductive diapause (Colares et al. 2015a).

For its part, *C. carnea* showed a linear increase in the consumption rate with an increase in prey abundance, with the slope of the curve representing searching efficiency (Fernández-Arhex & Corley 2004). This corresponds to a Type-I functional density-dependent response, where the highest prey-consumption response obtained was at a prey density of 64 aphids. The consumption rate of *C. carnea* at this aphid density was highly correlated with the number of days elapsed in the trial (r = 0.98, Fig. 3). The abundance of prey may have favored the development of this predatory insect, allowing for an increase in the prey capacity (b), that was 15.02 aphids on average per d. Liu and Chen (2001) reported similar results with different species of aphids.

The regression models for the rest of the aphid densities tested showed less steep slopes and smaller coefficients of determination (Fig. 3). Liu and Chen (2001) reported that not all aphid species are equally favorable for the growth and development of *C. carnea* and that the type of prey can influence the survival of this predator. However, Colares et al. (2015b) reported that *C. carnea* showed no difference in developmental time when feeding on *M. sacchari* or *S. graminum* (Rondani), and concluded that *C. carnea* was a predator suitable for the control of *M. saccahri*. *Chrysoperla carnea* has the potential to be used as an effective natural enemy for *M. sacchari* on sorghum because of its great consumption capacity and its ability to feed on various species of aphids, as well as on eggs and larvae of small lepidopteran species. Assemblages including both specialists and generalist predators, such as *H. convergens* and *C. carnea*, respectively, are particularly effective in reducing aphid populations (Diehl et al. 2013). In addition, the control of aphid populations by natural enemies is more effective when the aphids are feeding on grasses, such as sorghum, than when feeding on herbs or legumes (Diehl et al. 2013).

In the central region of Mexico, known as “El Bajio,” both the convergent ladybeetle and the common green lacewing are indigenous aphidophagous species present in different agroecosystems. This is the first study in Mexico to evaluate quantitatively the predatory rate of 2 potential native biocontrol agents for the recently arrived sugarcane aphid *M. sacchari*. Our results will contribute to the integrated pest management for this aphid. Promoting the presence of native natural enemies will help reduce the aphid populations in sorghum, and thus will help reduce the use of pesticides, such as imidacloprid, that has been associated with negative impacts in honey bee populations of *Apis mellifera* L. (Hymenoptera: Apidae) (Suchail et al. 2004).

Acknowledgments

We would like to thank M. McElroy for proofreading the manuscript, as well as the reviewers for their helpful suggestions.

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