

Life History of *Chrysoperla rufilabris* (Neuroptera: Chrysopidae) Provided Sweetpotato Whitefly *Bemisia tabaci* (Homoptera: Aleyrodidae) and Other Food

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We studied predation, development, longevity, survival, body length, head width, body weight, and prey preference of the predator, *Chrysoperla rufilabris* (Burmeister) (Neuroptera: Chrysopidae) feeding on the sweetpotato whitefly (SPW), *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae), *Aphis gossypii* Glover (Homoptera: Aphididae), an artificial diet (meridic casein-yeast), and eggs of *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae), *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae), and *Manduca sexta* (Linnaeus) (Lepidoptera: Sphingidae). *C. rufilabris* larvae attacked an average of 532 SPW per day when prey was mainly eggs. Development of *C. rufilabris* larvae was longer when SPW, aphids, or an artificial diet alone was provided. However, with a combination of eggs and first instars of SPW and an artificial diet or *S. cerealella* eggs, development of larvae was shortened with increased survivorship, adult emergence, and body weight. Larvae of *C. rufilabris* preferred *S. cerealella* eggs over *H. zea* and *M. sexta* eggs or *B. tabaci*. An artificial diet may be an appropriate supplementary food for rearing *C. rufilabris* where labor costs are high. The impact of *C. rufilabris* on sweetpotato whitefly population dynamics is discussed. © 1994 Academic Press, Inc.

KEY WORDS: *Chrysoperla rufilabris*; *Bemisia tabaci*; biological control; green lacewing.

INTRODUCTION

The green lacewing, *Chrysoperla rufilabris* (Burmeister) (Neuroptera: Chrysopidae) is a polyphagous predator in North America, east of Texas, and in central and northeastern Mexico (Smith, 1922; Tauber, 1974). *C. rufilabris* occurs in a variety of habitats including grasslands and crops (Smith, 1922; Tauber, 1974). *C. rufilabris* has potential as a biological control agent against several species of major insect pests, such as, Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Nordlund *et al.*, 1991); tobacco budworm, *Heliothis virescens*

(F.) (Lingren *et al.*, 1968; Nordlund and Morrison, 1990; Ridgway and Jones, 1969); corn earworm, *Helicoverpa zea* (Boddie) (Lingren *et al.*, 1968; Ridgway and Jones, 1969; Treacy *et al.*, 1987); cotton aphid, *Aphis gossypii* Glover (Homoptera) (Nordlund and Morrison, 1990); and sweetpotato whitefly (SPW), *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) (Breene *et al.*, 1992; Nordlund and Morrison, 1990; Onillon, 1990). Tauber and Tauber (1983) suggested that *C. rufilabris* is better adapted to humid, irrigated field or greenhouse conditions than is *Chrysoperla carnea* (Stephens). However, relatively few studies exist on the biology, ecology, and use of *C. rufilabris* for biological control of the sweetpotato whitefly or other insect pests.

B. tabaci is a major pest of various crops, including tomato, cole crops, cucurbits, and many ornamentals. *B. tabaci* damages plants by sucking their sap and by vectoring several diseases. In 1991, losses in cotton, vegetables, and fruits from SPW were estimated to exceed \$100 million in the Rio Grande Valley of Texas alone, and over \$200 million nationwide (USDA, 1992). Efforts to control SPW by biological control methods was identified as a high priority (Gerling, 1986; Onillon, 1990; USDA, 1992). Although *C. rufilabris* is already available commercially in the United States (Bezark, 1989), technology for its mass producing is continuously being improved (Nordlund and Morrison, 1992).

Food quality has a major influence on the success of rearing and survival of *C. rufilabris*. Eggs of Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae), or *H. zea* eggs have traditionally been used as food for rearing green lacewing larvae. Artificial diets have increasingly been used in recent years due to labor constraints in rearing prey and predator. Previous studies have shown that larval diet significantly affects larval mortality and development of *C. rufilabris* larvae and the weight of resulting adults (Hydorn and Whitcomb, 1979). Hydorn and Whitcomb (1979) reported an increase in fecundity and survival for *C. rufilabris* when *Drosophila melanogaster* (Diptera) and *Tribolium cas-*

taneum (Herbst) (Coleoptera) were replaced with aphids and *Phthorimaea operculella* (Zeller) eggs (Lepidoptera) as food.

Nordlund and Morrison (1990) found that *C. rufilabris* prefer *H. virescens* larvae over cotton aphids, *A. gossypii*, and *A. gossypii* over *H. virescens* eggs. The life history and prey preference of *C. rufilabris* feeding on *B. tabaci* is unknown. Thus, we studied predation rate, longevity, survival, development, body weight, and prey preference of *C. rufilabris* feeding on *B. tabaci* and other species of prey and on an artificial diet. Understanding the effect of food on the life history and prey preference of *C. rufilabris* will aid in determining the most effective food source for its mass production and augmentation for biological control programs.

MATERIALS AND METHODS

Life History of C. rufilabris Preying on *B. tabaci*

Green lacewing, *C. rufilabris*, specimens were obtained from a colony maintained by the USDA/ARS/SARL, Biological Control of Pests Research Unit at Weslaco, Texas, (Nordlund and Morrison, 1992). Sweetpotato whitefly, *B. tabaci*, specimens were obtained from infested Poinsettia cv. "V-14 Glory"¹ (cuttings from Ecker Farms, Encinitas, CA) in a greenhouse. The experiment was conducted with different ages of *B. tabaci* as prey in the laboratory at ambient temperature (20–23°C) from May 1992 to June 1992. Newly emerged first-instar *C. rufilabris* larvae were placed individually in plastic petri dishes (4-cm diameter) lined with damp cellulose support pads and secured with a rubber band and provided *B. tabaci* prey *ad libitum* (about 20–100 prey) until larvae molted to the second instar. After emergence of *C. rufilabris* larvae to the second instar, they were provided *B. tabaci* of different ages (eggs to fourth instars) *ad libitum* (high prey), 3 *B. tabaci* of different ages every 2 days (low prey), and no prey on an uninfested Poinsettia leaf (no prey).

Prey treatments were replicated five times except for those with no prey, which were replicated four times. After each 24-h feeding period, the number of prey consumed by *C. rufilabris* and the life history characteristics were recorded. Discolored eggs and dried and shrunk larvae and pupae were counted as having been attacked by *C. rufilabris*. In addition, head width and body length (from labrum to the tip of the abdomen) were measured at 8–9 days after the start of each feeding trial or at the time of a larvae's death.

Life History of C. rufilabris Feeding on Artificial and Natural Diets

Second-instar *C. rufilabris* larvae and frozen *S. cerealella* eggs were obtained from Rincon-Vitova Insectary (Oak View, CA). Frozen eggs of *H. zea* were obtained from the USDA/ARS/SPA Laboratory at Weslaco, Texas. Immature cotton aphids, *A. gossypii* were obtained from hibiscus plants in the greenhouse. The artificial diet was made of a meridic casein-yeast diet by the methods of Hassan and Hagen (1978). The artificial medium was composed of 5.0 g bee's honey, 5.0 g sugar, 5.0 g food yeast, 6.0 g yeast hydrolysate, 1.0 g casein hydrolysate, 10.0 g egg yolk, and 68.0 ml distilled water, to make up a total volume of 90 ml of the artificial medium. The sweetpotato whitefly was reared on lima beans (*Phaseolus limensis* L.). The experiment was conducted in the laboratory from July 1992–August 1992. Second instars of *C. rufilabris* were isolated individually in plastic petri dishes as described above and were given *S. cerealella* eggs. Subsequent feeding trials were *S. cerealella* eggs (40 mg), *S. cerealella* eggs (40 mg) + 100 *B. tabaci* eggs or first instars, 100 *B. tabaci* eggs or first instars, artificial diet (0.5 ml), artificial diet (0.5 ml) + 100 *B. tabaci* eggs or first instars, *H. zea* eggs (40 mg), 10 immature and adult *A. gossypii*, and control (no prey).

Each treatment was replicated 10 times. Food was provided in excess of the daily needs of *C. rufilabris* larvae. The length of time required for the lacewing larvae to molt from one instar to the next was recorded. Body weight of larvae was recorded at 1, 6, 11, and 15 days after the start of each feeding experiment using a Mettler analytical balance AT 200 (precision \pm 0.01 mg). Also, the body weight of the newly emerging adults was recorded. Newly emerged adults were dissected to determine gender. Developmental time and body weight for *C. rufilabris* feeding on the different food sources were analyzed by Kruskal-Wallis one-way analysis of variance and significantly different means were separated by Tukey's test (SYSTAT, 1989). A nonparametric test (Kruskal-Wallis) was used because the assumptions for a parametric test were not all met for each feeding trial.

Preference of C. rufilabris for Eggs of Different Species

The prey preference experiment was conducted in the laboratory in August 1992 with *C. rufilabris* larvae and frozen eggs of *S. cerealella* obtained from Rincon-Vitova Insectaries. Other prey used in the experiment, e.g., eggs of the tobacco hornworm, *Manduca sexta* (L.) (Lepidoptera: Sphingidae) and the corn earworm, were obtained from USDA/ARS Laboratory in Oxford, North Carolina, and USDA/ARS/SARL at Weslaco, Texas, respectively. Eggs and first instars of *B. tabaci* were from a colony from lima beans in the greenhouse.

Twenty second instars of *C. rufilabris* were isolated in

¹ This article presents the results of research only. Mention of a commercial or proprietary product does not constitute an endorsement or recommendation for its use by the USDA.

individual petri dishes (5 cm) lined with damp filter paper and starved for 4 h before the start of each feeding trial. Each treatment consisted of providing one *C. rufilabris* larva with a choice of four different prey species. Each dish was divided into four quadrats and 20 eggs of each prey species were placed in each quadrat. Larvae were placed at the center of each dish and observed for 5 min after release. Records were made of the species of prey that each larva consumed. Additional data were recorded 2 and 18 h after the release of larvae. The number of prey attacked was recorded 24 and 72 h after the start of each trial. The control consisted of one *C. rufilabris* larva per dish containing a lima bean leaf with no prey. Each trial and control was replicated 10 times. Body weight of larvae from each trial and control was recorded at the start and 24 and 72 h later. Data on the number of prey eaten were analyzed using an analysis of variance, and significantly different means were separated by Tukey's test (SYSTAT, 1989). A *t* test was used to compare differences between the body weight of larvae that were and were not provided prey (SYSTAT, 1989). A *t* test also compared the body weight of larvae from each treatment and control regardless of the time of measurement. All statistical tests were judged at $\alpha = 0.05$ except for the nonparametric test on development, where $\alpha = 0.10$.

RESULTS

Life History of C. rufilabris Preying on *B. tabaci*

All immature instars of SPW were preyed on by *C. rufilabris* larvae (Figs. 1A and 1B). The highest average total prey eaten was 531.5 (SE = 43.5) per larvae per day. More eggs of *B. tabaci* were consumed than first and second instars. For the low-prey treatment (3 prey every 2 days), *C. rufilabris* larvae consumed an average of 2.8 prey (SE = 0.2) each per day. Four days after the start of the experiment, 3 of the 5 larvae died and 10 days after the start of the experiment, all of the larvae under the low-prey treatment died. For predators that were provided a leaf only and no prey, 2 of the 4 larvae died 4 days after the start of each trial. Ten days after the start of each trial, all 4 larvae in the control died.

C. rufilabris larvae that were not given prey lived an average of only 6.5 days (SE = 1.5). Similarly, larvae that were provided three *B. tabaci* prey every 2 days (low prey) lived an average of 6 days (S.E. = 1.0). Whereas, larvae that were provided prey *ad libitum* lived an average of 17.5 days (SE = 3.88). The survivorship curve for larvae that were not provided prey shifted to the left, indicating a much lower survivorship compared with larvae that were provided prey *ad libitum* (Fig. 2). The survivorship curve for larvae provided three prey every 2 days was similar to that of the larvae that were not provided prey (Fig. 2).

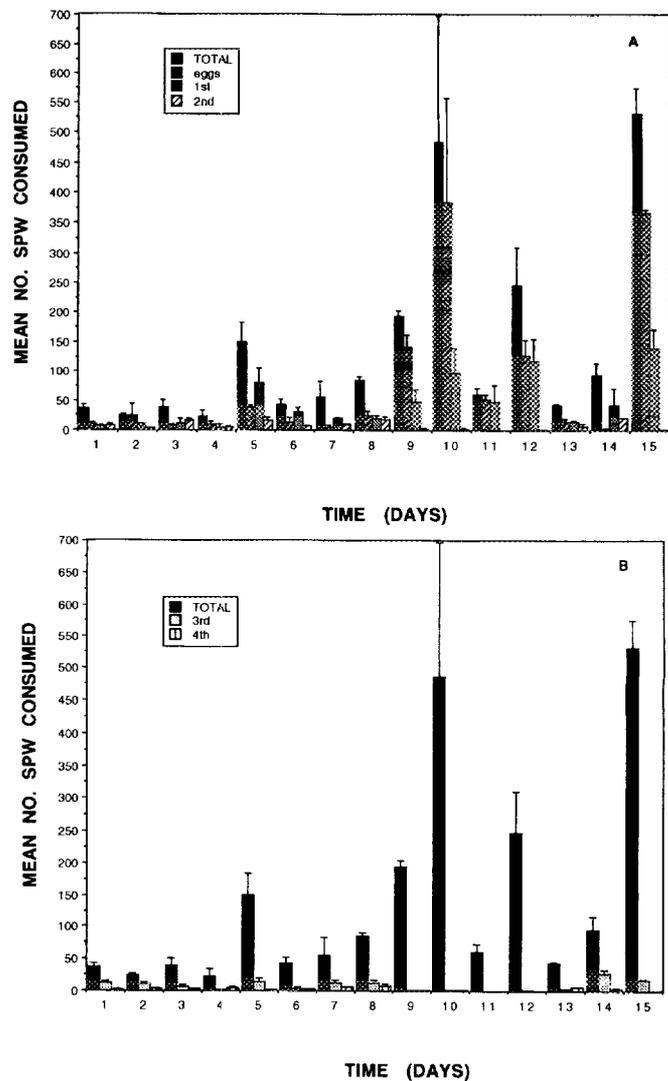


FIG. 1. *Bemisia tabaci* consumed as eggs and first and second instars (A) or third and fourth instars (B) by *Chrysoperla rufilabris* larvae through time (days). Error bars represent standard error.

The developmental time from second to third instar larvae was 3 days ($n = 1$) and 4.2 days ($n = 5$; SE = 0.58) when consuming three prey every 2 days and *ad libitum*, respectively. The average developmental time from second to third instars was 2.75 days ($n = 4$; SE = 0.25) for larvae that were not provided prey. Larvae not provided prey still molted to the third instar, 3–4 days after the start of the experiment. Only one larva provided three prey every 2 days molted to the third instar. Development from third instar to pupa for larvae in the low-prey treatment was not computed because larvae that were not provided prey died upon molting to the third instar. The longest of a third stadium occurred where a larva was provided prey *ad libitum* was 13 days before all the larvae died. Larvae provided prey *ad libitum* never pupated.

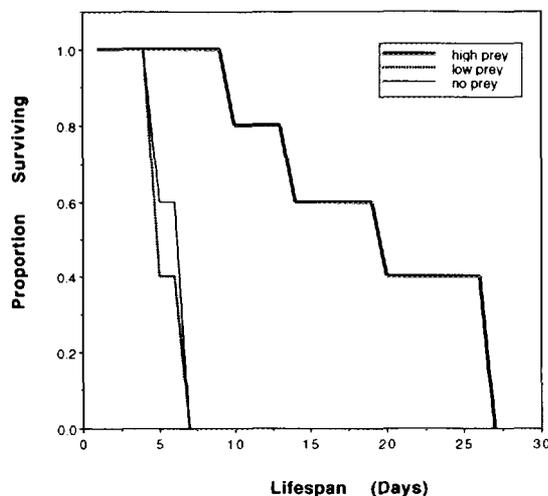


FIG. 2. Survival of *C. rufilabris* larvae provided different densities of the sweetpotato whitefly, *B. tabaci*. High prey represents prey provided *ad libitum* and low prey represents three *B. tabaci* as prey every 2 days.

Body length of third-instar *C. rufilabris* at 8–9 days after the start of the experiment was longest for larvae that were provided high prey inputs (5.0 mm, $n = 1$) followed by larvae that were provided no prey (mean = 4.90 mm, SE = 0.10, $n = 2$) and low-prey inputs (mean = 3.95 mm, SE = 0.35, $n = 2$). Similarly, head width was widest in larvae under the high-prey treatment (1.0 mm) followed by larvae provided no prey (mean = 0.95 mm, SE = 0.05) and low-prey inputs (mean = 0.7 mm, SE = 0.03).

Life History of *C. rufilabris* Feeding on Artificial and Natural Diets

Development of second and third instars of *C. rufilabris* varied as a function of diet (Fig. 3). Significant differences ($P < 0.09$) occurred in the development of second-instar *C. rufilabris* using the different diets. Development was significantly shorter for second instars provided *S. cerealella* eggs (mean = 3.80, SE = 0.25) than that for those larvae provided the artificial diet (mean = 6.38, SE = 0.89). Development for second-instar larvae that were provided *H. zea* eggs was significantly shorter than the development for larvae provided a combination of *S. cerealella* eggs and sweetpotato whitefly and those on artificial diet. No significant differences were found in the development of third instars or pupae and total development time under the different treatments. Larvae of *C. rufilabris* provided sweetpotato whitefly and aphids alone, and those not provided food, died as third instars, usually in the act of molting.

Survival of larvae feeding *S. cerealella* eggs, *S. cerealella* eggs and *B. tabaci*, *H. zea*, and the artificial diet was similar (Fig. 4A). In contrast, survival of larvae pro-

vided *B. tabaci*, aphids, and the artificial diet and *B. tabaci* decreased (Fig. 4B). Larvae that were not provided food (controls) died by Day 6 after the start of the experiment, usually while molting to the third instar (Fig. 4B).

Significant differences ($P < 0.04$) in body weight of the larvae were found between the different treatments at Day 1 after the start of the experiment (Fig. 5). This is probably due to the decrease in body weight of the larvae that were not provided food. Predators that were provided SPW and aphids had the lowest body weights and failed to reach the pupal and adult stage. No significant differences in body weights of *C. rufilabris* were found between the treatments on Days 6, 11, and 15 (third instar) after the start of the experiment and the adult stage.

The number of males (m) to females (f) emerging from larvae feeding on the different diets was *S. cerealella*, 2m:2f; *S. cerealella* and *B. tabaci*, 4m:1f; artificial diet, 3m:3f; artificial diet and *B. tabaci*, 1m:1f; and *H. zea*, 7m:0f. Larvae provided the artificial diet and *H. zea* eggs produced 1 and 3 adults, respectively. The emerging adults had undeveloped wings and died 1–3 days after emergence.

Preference of *C. rufilabris* for Eggs of Different Species

Based on visual observations, most *C. rufilabris* larvae moved to *S. cerealella* and *H. zea* eggs during the first 5 min after their release. One larvae moved to *M. sexta* eggs but it did not attack them. Two hours after their release, a few larvae were feeding on *S. cerealella* and *H. zea* eggs, and more larvae were resting on the dish or under the leaves. Eighteen and 24 h after the start of the trials, most of the larvae were resting on the dish. *C. rufilabris* larvae pierced *M. sexta* eggs, but they did not feed long. Significant differences were found in the num-

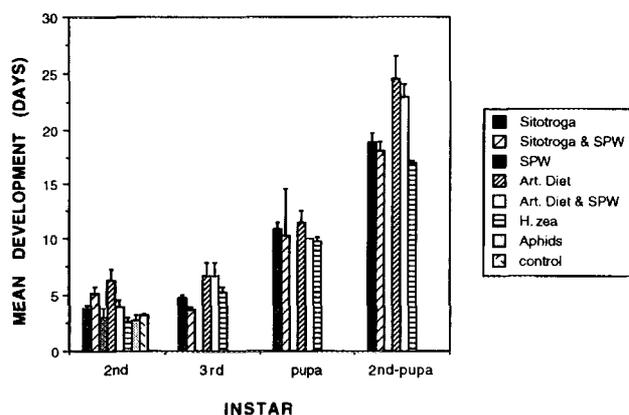


FIG. 3. Average developmental time for *C. rufilabris* feeding on different species of prey and on artificial medium. Error bars represent standard error.

ber of prey eaten by *C. rufilabris* larvae 24 and 72 h after release. *C. rufilabris* larvae seemed to prefer *S. cerealella* eggs and *H. zea* as prey, followed by *B. tabaci* and *M. sexta* eggs. Twenty-four hours after release of *C. rufilabris* larvae, the latter consumed a mean \pm SE of 19.0 ± 0.99 , 14.6 ± 1.99 , 9.3 ± 1.47 , and 4.6 ± 0.96 eggs of *S. cerealella*, *H. zea*, *B. tabaci*, and *M. sexta*, respectively. Seventy-two hours after release of the larvae, they consumed a mean \pm S.E. of 19.5 ± 0.50 , 18.2 ± 0.93 , 15.0 ± 0.97 , and 4.9 ± 1.64 eggs of *S. cerealella*, *H. zea*, *B. tabaci*, and *M. sexta*, respectively. The least preferred prey was *M. sexta*. Body weight (mg) was not significantly different for larvae provided prey (mean \pm S.E. = 1.75 ± 0.14) and larvae without prey at the start of the experiment (1.90 ± 0.27). After 24 h, larvae that were provided prey (3.87 ± 0.41) weighed significantly more than larvae not provided food (2.17 ± 0.32). However, after 72 h, no differences were found between larvae with prey (5.13 ± 1.06) and larvae without prey (1.78 ± 0.39). This result

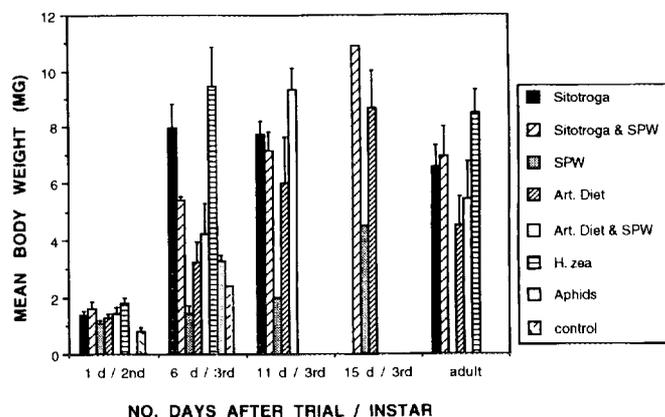


FIG. 5. Average body weight of *C. rufilabris* feeding on different species of prey and an artificial medium. Error bars represent standard error.

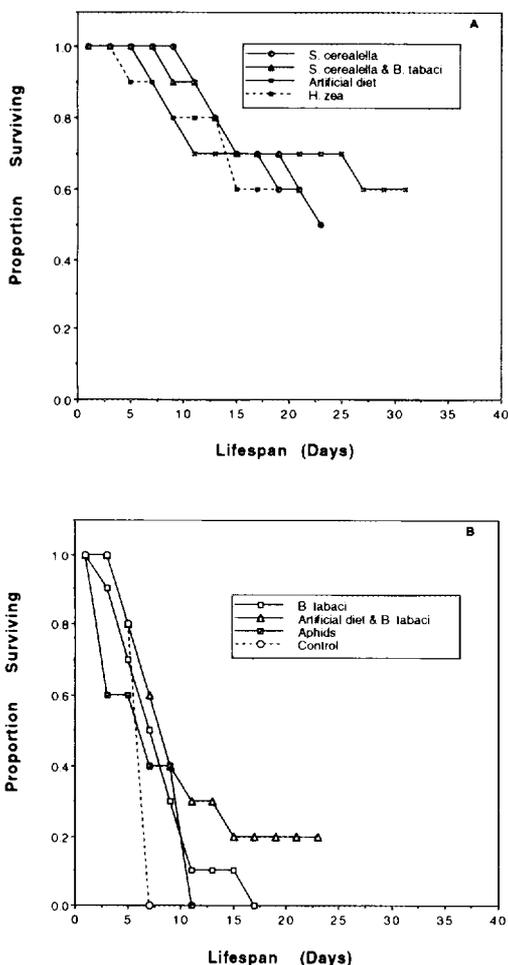


FIG. 4. Survival of *C. rufilabris* larvae feeding on *S. cerealella*, *S. cerealella* and *B. tabaci*, an artificial diet, or *H. zea* (A) or *B. tabaci*, an artificial diet and *B. tabaci*, *A. gossypii*, or no prey (B).

may be due to the lack of replicates in the control ($n = 4$) because the predators died of starvation. Regardless of the time the measurements were made, predators that were provided prey had higher body weights compared to those that were not provided prey.

DISCUSSION

All immature stages of *B. tabaci* were preyed on by *C. rufilabris* larvae. However, a high number of *B. tabaci* was needed for larval development to the third instar. Larvae that were provided prey *ad libitum* lived about three times longer than larvae that were provided three prey every 2 days. Development of *C. rufilabris* larvae was longer when given *B. tabaci* compared to *C. rufilabris* larvae provided lepidopteran prey (Or and Gerling, 1985; Tauber and Tauber, 1983). *C. rufilabris* larvae that were provided three *B. tabaci* as prey every 2 days had similar longevity and survival as larvae that had no prey. Apparently, *C. rufilabris* larvae that were not provided prey received nutrition from plants. The importance of plants in increasing survival and development of generalist predators especially when prey is unavailable has been documented (Legaspi and O'Neil, 1993; Ruberson *et al.*, 1986; Stoner, 1970; Stoner *et al.*, 1974; Wiedenmann and O'Neil, 1990a,b).

Larvae of *C. rufilabris* that were provided prey *ad libitum* were larger than larvae that were provided three *B. tabaci* every 2 days or no prey; however, none developed to the adult stage. It is possible that sweetpotato whitefly reared on poinsettia or lima bean were nutritionally inadequate (Hydorn and Whitcomb, 1979) for *C. rufilabris* development, or *B. tabaci* reared on lima bean may have an accumulative toxic effect on *C. rufilabris*. The presence of a toxin in lima bean was suspected since more sweetpotato whitefly developed on cucumber and

cantaloupe than on lima bean (Legaspi *et al.*, unpublished data).

The diet of *C. rufilabris* apparently affects the development, survival, adult emergence, and body weight of newly emerged adults. Larvae that were provided *H. zea* and *S. cerealella* eggs developed faster, had an increased survival, and weighed more as newly emerged adults than larvae that were fed on a combined diet of lepidopteran eggs and SPW or on an artificial diet. Larvae feeding on artificial diet as their main food developed to the adult stage, but their development was slower than the development of larvae that were provided *H. zea* and *S. cerealella* eggs. A diet of *B. tabaci* or aphids alone did not enable larvae to reach the adult stage. However, diet combining *S. cerealella* eggs or an artificial diet with *B. tabaci* enabled *C. rufilabris* to develop to the adult stage.

Prey preference for *C. rufilabris* larvae probably is a function of its quality. Since *C. rufilabris* developed faster and larval mortality was lower when *S. cerealella* and *H. zea* eggs were provided as food, it is expected then that *C. rufilabris* would prefer *S. cerealella* and *H. zea* eggs. The latter are bigger than *B. tabaci*; however, *M. sexta* eggs are bigger than *H. zea* or *S. cerealella* eggs. Thus, prey size alone may not be a factor in food preference for *C. rufilabris* larvae. Other cues, e.g., chemicals produced by the prey, texture of the prey, and handling time may be involved in prey preference. Nutritional quality of a prey obviously is a factor to consider for prey preference. Further nutritional studies on the quality and quantity of carbohydrate, fat, and protein obtained from different types of prey will increase our understanding of prey preference by *C. rufilabris*.

During our trials, *C. rufilabris* showed that the predator spent a substantial amount of time "resting." We found *C. rufilabris* larvae mainly under plant leaves, on the lower surface of the cover of petri dishes, and on the lower surface of the filter paper at the bottom of the dish (personal observation). Other workers have demonstrated that resting behavior may be an adaptive strategy by generalist predators, such as the spined soldier bug, *Podisus maculiventris* (Say) (Pentatomidae) (Wiedenmann and O'Neil, 1991), and *Geocoris punctipes* (Lygaeidae) (Cohen, 1985), to conserve energy and prevent water loss under stressful conditions. Further analysis of the behavior of *C. rufilabris* and corresponding measurement of their metabolic rates under different feeding conditions are warranted.

Differences in life history characteristics of *C. rufilabris* larvae feeding on different diets will impact mass production for commercial or research purposes. Where labor expenses are high, the use of an artificial diet as a supplementary food may increase profits. However, if labor is not considered an economic constraint, use of natural prey may be a better approach to increase production and profits. The contribution of *C. rufilabris* in controlling the sweetpotato whitefly, *B. tabaci*, may be

limited. In fields heavily infested with whiteflies, the use of *C. rufilabris* larvae may be desirable when their longer duration of development will mean a longer period for *C. rufilabris* to feed on whiteflies and thus a longer "residence time" for the predator to affect the population dynamics of *B. tabaci*. Where other prey are present, such as, lepidopteran pests, *C. rufilabris*' development may be shorter and it may thus better synchronize and control sweetpotato whitefly populations. However, if lepidopteran eggs are preferred prey for *C. rufilabris*, it may not contribute significantly in reducing SPW population in the field when other prey are available.

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