Interactions Between *Cycloneda sanguinea* and the Brown Citrus Aphid: Adult Feeding and Larval Mortality

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ABSTRACT The number of *Toxoptera citricida* eaten per day by *Cycloneda sanguinea* varies in proportion to the densities of the aphid. Functional responses for the predator male and female adults corresponded to that of Holling's type II. *C. sanguinea* immatures failed to develop to the adult stage when fed either live brown citrus aphid or dry brown citrus aphid meal. However, successful development was achieved with larvae fed dry meal of the aphid *Dactinotus ambrosiae* (Thomas). This suggests that *T. citricida* is nutritionally inappropriate for or is toxic to *C. sanguinea*. Although adults and, initially, larvae of *C. sanguinea* were voracious predators of *T. citricida*, the lack of complete development of the larval stage would likely limit its use in pest management of the brown citrus aphid.

In VENEZUELA, the lady beetle, *Cycloneda sanguinea* L., feeds on aphids and other insect pests common to several crops (Szumkowski 1955). It has been described as an efficient predator (Gurney and Hussey 1970, Gravena et al. 1977). Recently, it has been found in orange orchards feeding on the brown citrus aphid, *Toxoptera citricida* (Kirkaldy) (Gutiérrez and Díaz 1978, Geraud 1979), a pest considered the most important vector of the viral citrus disease, tristeza. This discovery has stimulated interest in *C. sanguinea* as a possible biological control agent of the brown citrus aphid.

No specific studies quantifying the relationship between *C. sanguinea* and *T. citricida* have been undertaken. Tao and Shui (1971), however, have reported injury or death of some coccinellid species fed *T. citricida* exclusively. Other coccinellids were unaffected. The suitability of *T. citricida* as prey of the lady beetle must therefore be determined to gauge capacity of *C. sanguinea* to maintain significant numbers in affected orchards.

In this paper we examine the effects on *C. sanguinea* of feeding on *T. citricida* and the consumption of the aphid at various prey densities.

Materials and Methods

Lady beetle adults were collected in Venezuela from the locally abundant weed *Launea intybacea* (Jacq.) Beauv. and from corn, *Zea mays* L. The beetles were brought to the laboratory and separated by sex (Chapin 1974).

Thirty males and 30 females isolated in separate petri dishes (15 cm diam) were provided with a 2-dram, cotton-stoppered vial of water and fed brown citrus aphids. The aphids were collected on citrus stems (*Citrus* spp.) at the Universidad Centro Occidental "Lisandro Alvarado" Experiment Extension Farm, Tarabana, Lara State. Stems bearing the aphids were pruned, dropped inside paper bags, and transported to the laboratory. Both the predator and the prey were maintained in a constant temperature chamber at 25 ± 0.5°C, 75 ± 10% RH, and a photoperiod of 10:14 (L:D).

Adult males and females were selected at random from petri dishes and maintained with water but without food for a period of 12 h before the start of feeding trials. Each feeding trial consisted of five treatments, one at each of the densities 10, 20, 30, 40, and 50 aphids per container. Four replications were run.

The containers used were 456-ml plastic cups fitted with two lateral mesh windows and a mesh lid. The mesh (37 by 39 strands per cm^2) allowed maintenance of proper relative humidity and air circulation through the cages. To each container was added the appropriate number of fourth-instar aphids and two fresh citrus leaves. Cups were checked at 12-h intervals and the number of aphids consumed or partially consumed by each male or female predator was recorded. Appropriate prey densities were restored by replacing any consumed, partially consumed, or dead aphids. Feeding trials were terminated after 7 days.

Adult female lady beetles collected in the field were used to obtain eggs. Single females were placed inside the described plastic cups along with two fresh citrus leaves, sufficient brown citrus aphids, and moistened cotton-stoppered vials. The cups were checked once every 12 h. Leaves with deposited eggs were isolated in other similar cages until larvae hatched.

Larval feeding trials were conducted using methods similar to those described for the adults. To reduce disturbance during larval molting, how-

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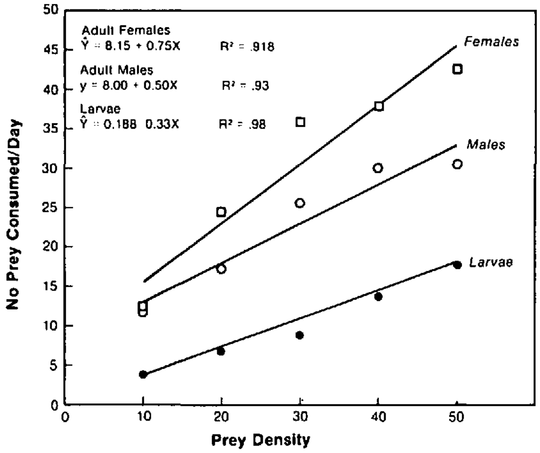

Fig. 1. Functional response of *C. sanguinea* feeding on *T. citricida* (linear model).

ever, cups were checked only once daily. Upon hatching, first instars were placed into separate cups at the previously mentioned densities. Development through the larval stages was assessed by observing the exuviae left in the cup by each instar. Numbers of individuals in each instar were tallied daily.

Experiments also were conducted to determine duration (days) for development of the immature stages of the predator fed on meals made from the brown citrus aphid or another aphid species, *Dactinotus ambrosiae* (Thomas). The latter was collected in the field on *L. intybacea* by cutting the host plant and dropping it into paper bags. Brown citrus aphids were collected on citrus, as previously described. Within 1 h after collection, the aphids were killed by freezing at −15°C, separated from other insects and debris by means of sieves, and crushed with a mortar and pestle. The crushed aphids were desiccated at room temperature and then ground to a powder of particles not larger than 500 μm. The resulting meal was stored at −15°C.

Lady beetle eggs were obtained in the laboratory as indicated above. A single first instar of *C. sanguinea* was placed into each of 24 plastic cups previously described. Twelve of these larvae were fed with brown citrus aphid meal; the other 12 were given the *D. ambrosiae* meal. Water was supplied through a moistened cotton-stoppered vial. Chamber conditions were the same as previously mentioned. The number of individuals at each instar was recorded at 12-h intervals.

Table 2. Average number of brown citrus aphids eaten per day by *C. sanguinea* adults and first instars at different prey densities

Prey density	Male adults (mean ± SE)	Female adults (mean ± SE)	First-instar larvae[a] (mean ±SE)
10	11.9 ± 0.36	12.5 ± 0.44	4.0 ± 0.44
20	17.1 ± 0.47	24.4 ± 0.79	6.9 ± 0.99
30	25.6 ± 0.65	35.9 ± 0.89	8.8 ± 0.98
40	30.0 ± 0.73	37.8 ± 1.09	13.6 ± 1.00
50	30.5 ± 0.60	42.6 ± 0.99	17.2 ± 1.33

[a] Feeding response was computed only for first instars due to lack of complete development through subsequent instars.

Two mathematical models, linear and Holling (Holling 1959, 1961), were applied to the feeding response data using linear regression analysis to estimate the relationship between the number of prey eaten per day and prey density for adult males and females of *C. sanguinea*. The model to data fit was evaluated by F and r^2 statistics. Means and standard errors were computed to determine time of development for the predator larval stages feeding on dry *D. ambrosiae* and *T. citricida* meals.

Results and Discussion

First instars of *C. sanguinea* fed voraciously at all aphid densities and all reached first ecdysis. However, many of the larvae died at the second and third ecdysis. Only 5 of 20 reached the third instar, and none became prepupae. Results were corroborative for larvae fed on dry brown citrus aphid meal. Only 2 of the 12 first instars fed dry *T. citricida* reached the fourth instar, and none survived to the prepupa stage. In contrast, all 12 larvae of the predator fed on dry *D. ambrosiae* successfully developed to the adult stage (Table 1). The surviving *C. sanguinea* second instar fed on dry *T. citricida* required more time for development than did those reared on dry *D. ambrosiae*. These findings indicate that *T. citricida* is an inadequate prey for immature *C. sanguinea* due to nutritional dietary factors, toxicity, or both.

Consumption rate of aphids by male and female adults and first instar larvae increased with greater prey density (Table 2). The female predator consumed more prey than the male or the first instar larvae at all prey densities. The greater consump-

Table 1. Development of *C. sanguinea* larvae fed dry *T. citricida* and *D. ambrosiae*

Species	1st Instar	Development time in days (mean ± SE)			Prepupa	Pupa
		2nd Instar	3rd Instar	4th Instar		
T. citricida	5.2 ± 0.79	4.7 ± 0.66	4.5 ± 0.50	—	—	—
n	12	6	3	2	—	—
D. ambrosiae	3.5 ± 0.15	2.5 ± 0.15	4.2 ± 0.32	5.5 ± 0.23	1.2 ± 0.11	4.3 ± 0.14
n	12	12	12	12	12	12

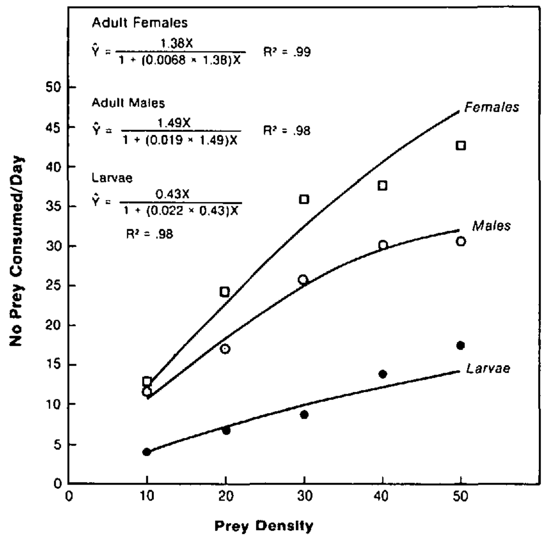

Fig. 2. Functional response of *C. sanguinea* feeding on *T. citricida* (Holling model).

tion rate for adult female lady beetles compared with males corresponds with feeding behavior noted in other insect predators (Hull et al. 1977).

Analysis of the feeding response data for *C. sanguinea* adult males and females showed significant F values and high coefficients of determination, r^2, for both linear and Holling models, indicating a strong correlation between number of prey consumed per day and prey densities[2] (Fig. 1 and 2). The somewhat higher r^2 value for the Holling model might have been more pronounced if higher prey densities had been included.

Although the voracity of *C. sanguinea* and its functional response to *T. citricida* are desirable characteristics, the lethality of the aphid to the lady beetle larvae may preclude use of this predator in biological control of the pest. However, in orchard areas where lady beetle populations exist autochthonously their contribution to brown citrus aphid control may be significant.

An interesting question arises as to whether the lethality of the aphid is due to nutritional inadequacy or toxic compounds and whether this characteristic is inherent to the aphid or is acquired by feeding on citrus. Field studies might help explain the origin and stability of lady beetle populations in citrus orchards infested by the brown citrus aphid. Additional investigation involving other predators or parasites will be needed to establish suitable biological control of *T. citricida* in citrus orchards.

[2] For females: linear equation F value = 33.56 ($P < 0.05$); Holling equation F value = 122.80 ($P < 0.01$). For males: linear equation F value = 40.01 ($P < 0.01$); Holling equation F value = 26.40 ($P < 0.05$).

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