# Reproduction and Feeding Behavior of *Delphastus pusillus* (Coleoptera: Coccinellidae), a Predator of *Bemisia tabaci* (Homoptera: Aleyrodidae)

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**ABSTRACT**   The development, feeding behavior, fecundity, and longevity of *Delphastus pusillus* (LeConte) on the whitefly *Bemisia tabaci* (Gennadius) was studied in the laboratory at 28 ± 3°C. Developmental time from oviposition to eclosion was 21.0 d. Longevity of adults was 60.5 d for females and 44.8 d for males. Larval and adult beetles fed on all stages of whitefly. The number of prey consumed by adult beetles decreased with increasing age and size of prey; i.e., 167.1 eggs or 11.6 early fourth instars per day. Handling time increased with stage of whitefly, from 31.3 s for eggs to 377.7 s for early fourth instars. Beetle larvae began feeding upon hatching and consumed a mean of 977.5 eggs before pupating. Mated females laid eggs only when reared on diets containing whitefly eggs. When reared exclusively on a diet of eggs, beetles laid 3.0 eggs per day. Mean lifetime egg production was 183.2. Predation on *B. tabaci* eggs and beetle oviposition was also observed in a greenhouse; mean prey consumption was 51% greater and mean daily oviposition by females was 103% higher than in the laboratory. Between 100 and 150 whitefly eggs per day were required to initiate and sustain oviposition in the laboratory and the greenhouse. The need for large numbers of whitefly eggs in the diet suggests *D. pusillus* will maintain itself without augmentation only in large populations of *B. tabaci*.

**KEY WORDS**   *Delphastus pusillus*, *Bemisia tabaci*, predation

SWEETPOTATO WHITEFLY, *Bemisia tabaci* (Gennadius), is a worldwide tropical and subtropical pest of many field crops (Anonymous 1986), especially cotton and vegetables. Damage to plants is caused by reduction in plant vigor and production of honeydew on which sooty molds develop. *B. tabaci* also vectors many plant pathogenic viruses (Costa 1976) and recently has been found to induce growth disorders in some ornamentals and vegetables (Schuster et al. 1990, 1991; Yokomi et al. 1990; Hoelmer et al. 1991). Although *B. tabaci* was reported from the United States as early as 1894 (Russell 1975), it was seldom a serious problem in the United States until outbreaks began to occur in Arizona and California in 1981 (Johnson et al. 1982) and in Florida in 1986 (Hamon & Salguero 1987).

Numerous predators and parasitoids have been associated with *B. tabaci* (Lopez Avila 1986), but there are no published studies of its natural enemies in the southeastern United States. Preliminary surveys indicate that some species indigenous to the region now attack *B. tabaci* (Bennett et al. 1990, Hoelmer & Osborne 1990). One native predator often found associated with large populations of whiteflies in Florida is *Delphastus pusillus* (LeConte). The adult *D. pusillus* is a small shiny black beetle 1.3–1.4 mm in length, and the larva is pale yellowish white. This coccinellid has been reported as a predator of various aleyrodids on citrus in Florida (Muma 1956, Cherry & Dowell 1979), of citrus blackfly, *Aleurocanthus woglumi* Ashby in Mexico (Smith et al. 1964), and of *Aleurotrachelus socialis* Bondar and *Trialeurodes variabilis* (Quaintance) on cassava in Colombia (Gold & Altieri 1989). All known members of the genus *Delphastus* Casey have been described from the Nearctic and are known predators of whiteflies. *D. pusillus* is widely distributed across the central and southern United States and south through Central America into South America as far as Peru (Gordon 1985).

The objectives of our study were to determine the life history and basic rearing requirements for *D. pusillus* on *B. tabaci* and to provide a preliminary assessment of its potential as a biological control agent of *B. tabaci*.

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## Materials and Methods

Our insectary colonies of *D. pusillus* were started with feral beetles collected from central Florida and maintained in a greenhouse and in a laboratory insectary room on *B. tabaci* reared on *Phaseolus limensis* Macfady cv. Henderson, *Euphorbia pulcherrima* Willd. ex Klotzsch, *Hibiscus rosa-sinensis* L., and the whitefly *Trialeurodes variabilis* (Quaintance) (reared on *Carica papaya* L). Voucher specimens have been placed in the Florida State Collection of Arthropods, Gainesville.

Laboratory studies were conducted at 28 ± 3°C with a 12:12 (L:D) h photoperiod. A stereomicroscope was used to count whitefly eggs and nymphs (given to and consumed by beetles) and beetle eggs laid.

**Developmental Studies.** Beetle eggs were obtained from the insectary colony or from females in the laboratory. We initially tried to control the supply of available eggs by storing them at low temperatures to slow their development, but eggs were killed after storage overnight in a refrigerator ≤6°C. Even at 10°C, viability of eggs stored was higher, but still lower than that of uncooled eggs. Therefore, all eggs used in experiments were fresh. To minimize damage from handling, beetle eggs were isolated on leaf disks and placed individually on moist filter paper or on 5% agar gel in petri plates kept on a bench in the laboratory. *Methyl parabenzoate* (methyl P-hydroxy-benzoate) was added to the agar to retard growth of bacterial and fungal contaminants. Neonate beetle larvae were provided daily with new leaf sections containing several hundred *B. tabaci* eggs (1–2 d old). Data on egg consumption and molting were recorded daily for six males and six females throughout completion of their larval and pupal development.

**Longevity Studies.** Beetle pupae were collected from the insectary colony and held in the laboratory in petri dishes until emergence. Newly emerged adults were placed individually in plastic petri dishes containing moist filter paper and kept in the laboratory. Females were confined with two or three males for 24 h for mating, after which males were removed. Beetles were given leaf disks with ≥300 *B. tabaci* eggs every day. Consumption of whitefly eggs by male and female beetles and oviposition by female beetles were recorded each day.

**Feeding Studies.** Whitefly death from predation by beetles was readily distinguished from other mortality factors, thus allowing us to accurately count individuals consumed. A high-resolution video camera with monitor was used for observations of feeding behavior. Individual beetles were studied in polystyrene petri plates (10 by 35 mm) with lids cut out and fitted with mesh screening to allow ventilation and prevent condensation. Handling time and maximum daily consumption of each stage was determined by observing individual beetles in these experimental arenas. Beetles were provided with one of the following diets: 200–300 eggs; 200–300 first instars; 100–150 second instars; 50–75 third instars; or 30–40 fourth instars (prepupae). Beetles were transferred daily to new plates containing fresh leaf disks with whiteflies of the desired stage. Only female beetles observed feeding in laboratory colonies were used for these studies. Oviposition, if any, was recorded. Egg consumption was recorded only from apparently healthy individuals that fed consistently for at least 5 consecutive d.

Feeding studies were also done in the greenhouse for purposes of comparison with the results of the laboratory studies. Individual female adult beetles were confined to single hibiscus leaves with leaflet cages. Leaves contained an abundant supply of whitefly eggs and nymphs of all stages. These leaves were examined with a binocular microscope while still attached to ensure that only healthy whiteflies were initially present. The daily temperature range in the greenhouse was 24–33°C during these studies. After feeding for 24 h, the beetles were transferred to a new leaf. Prey consumption was evaluated by clipping the leaf for examination with a stereomicroscope and recording the number of each stage eaten.

**Oviposition Studies.** Oviposition by *D. pusillus* fed to satiation with whitefly eggs was recorded from the longevity studies conducted in the laboratory. The relation between quantity of whitefly eggs consumed and beetle fecundity was examined by using petri dishes as experimental arenas as previously described. Because unmated female beetles did not lay eggs, newly eclosed females were confined for 1–2 d with males for mating. Beetles taken from laboratory colonies were assumed to have mated. Females selected for these studies were given ≥350 eggs per day until oviposition was observed to confirm their reproductive status. Six to eight females were then placed on each of five diets: ≥350, 200, 150, 100, or 50 whitefly eggs per day. Leaf disks with whitefly eggs were changed daily, and the numbers of eggs consumed and beetle eggs produced were recorded every day for 9 d. Females that did not feed consistently were eliminated from the study, leaving at least four to six females in each group. This experiment was conducted in a greenhouse (temperature and humidity range during the experiment was 19–30°C and 60–95% RH daily).

To observe the effect of varying the diet of an individual beetle on her fecundity, a second group of 19 females (six reared from pupae and 13 collected from the insectary colony) were fed ad lib until oviposition was observed. They were then given a diet of 50 eggs per day for 5 d. Numbers of eggs were increased to 100 eggs per

**Table 1. Developmental time of *D. pusillus* reared in the laboratory at 28°C**

| Parameter | Developmental time (d) at stage | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Egg | 1 | 2 | 3 | 4 | 4 (pupating) | 5 | Pupa |
| Mean | 4.1 | 1.8 | 1.4 | 1.8 | 1.7 | 2.9 | 2.0 | 6.1 |
| SD | 0.6 | 0.8 | 0.5 | 0.9 | 0.9 | 2.1 | 0.8 | 0.7 |
| Range | 3–5 | 1–3 | 1–2 | 1–3 | 1–3 | 1–7 | 1–3 | 5–7 |
| n | 16 | 16 | 14 | 12 | 3 | 4 | 3 | 16 |

day for the second 5 d, then increased again to 150 eggs per day for the final 5 d. Oviposition by beetles was recorded each day. Mean oviposition on each diet in both experiments was compared using the multiple stage test (REGWF; SAS Institute 1982) with the statistical software CRISP (Stegner & Bostrom 1984).

The influence on beetle fecundity of mixing different whitefly stages in the diet was investigated in the laboratory by comparing oviposition of mated female beetles reared on four diets for 21 consecutive days. Diet regimes were (1) whitefly eggs only (*n* = 7); (2) eggs provided only until oviposition was noted, after which only fourth instars were given (*n* = 8); (3) a combination of 15 fourth instars and 25 eggs daily from hatching (*n* = 8); and (4) a combination of 15 fourth instars and 50 eggs daily from hatch (*n* = 10). Other experimental procedures were done as described above.

## Results

**Developmental Biology.** At 28°C, eggs hatched in 3–5 d (Table 1). Instars lasted between 1.4 and 3.0 d. About half of the fourth instars molted to a fifth instar. This stadium lasted 2.0 d; the rest pupated without the extra instar. The duration of the pupal stage was 6.1 d. Development time was $21.0 \pm 1.5$ d from egg to adult for females and $21.1 \pm 1.5$ d (mean $\pm$ SD) for males (*n* = 20 for each).

**Adult Longevity.** Newly emerged adult beetles are pale in color and remain inside the opened pupal cuticle for several hours. Newly emerged females did not mate as readily as those 24 h or older. When mated females were needed for oviposition studies, several males were confined for 16–24 h with each female to ensure mating. Adult female longevity in laboratory studies averaged $60.5 \pm 24.3$ d (range, 26–93; *n* = 15). Male survival averaged $44.8 \pm 6.25$ d (range, 39–54; *n* = 6).

**Feeding Behavior.** Beetles used their maxillary palpi to probe the leaf surface for prey while walking. Detection of prey at short range appeared to require contact. *D. pusillus* was observed to walk past whiteflies if no actual contact occurred. Videocamera observations showed that adult and larval *D. pusillus* fed by biting through the whitefly integument and extracting the contents. When feeding on older nymphs, *D. pusil-*

*lus* frequently regurgitated, thereby reinflating the prey and introducing air bubbles. The internal contents of the whitefly were agitated during this process, possibly helping to liquify or digest them for extraction. The oral morphology of *D. pusillus* was not studied, but larvae of other small coccinellids have an internal duct within the mandibles for extraction and extraoral digestion of liquid food (Savoiskaya 1960).

Beetles generally fed only on the internal contents of their prey, leaving the collapsed cuticle of eggs and immatures after feeding. When beetles fed on whitefly eggs, the entire shell, except for the base inserted into the leaf, was consumed ≈10–15% of the time. Nymphs that died from causes other than beetle predation left behind dried or discolored internal organs visible through the cuticle. Feces (watery or pasty yellowish deposits) were often deposited on or near whiteflies, providing characteristic indirect evidence of beetle feeding activity. Puncture wounds in the cuticle were not usually detectable and therefore were not a reliable indicator of predation. Indirect evidence of predation could be useful in evaluating the effect of predation by *D. pusillus* in the field. We frequently saw such evidence of feeding activity on field-collected foliage.

Consumption (prey-handling) time by first, second, and fourth instars and adult female beetles generally increased within each beetle age class with increasing age and size of whitefly stage (Table 2). Handling times for whitefly eggs and early instars were similar for fourth instar and adult beetles, but fourth instars required less time to consume older whitefly prey. First and second instars expended more time than fourth instars and adults in consuming whitefly eggs and immatures. Older nymphs were seldom attacked, however, especially when younger stages were available. This preference may be because of the increased difficulty in penetration of the cuticle, which has been noted with other coccinellid larvae (Drea 1956).

*Delphastus pusillus* larvae were often observed to congregate in the same area on the same leaf disk even when several were available. Larvae occasionally competed with one another while feeding by bumping each other away from prey. Larval and adult beetles occasionally fed on beetle eggs and early instars; this seldom occurred if whitefly prey was abundant.

Table 2. Mean handling time in seconds (SD) by instars and adult females of *D. pusillus* during consumption of immature stages of *B. tabaci*

| *D. pusillus* stage | *B. tabaci* stage | | | | | |
|---|---|---|---|---|---|---|
| | Egg | 1 | 2 | 3 | 4 | Pupa |
| Instar | | | | | | |
| 1 | 428.2  (87.3) | 691.0 (434.3) | 922.5 (601.4) | 2,178.3 (1,522.7) | — | — |
| 2 | 295.8 (115.4) | 113.5  (33.2) | 205.0 (165.9) | 575.6  (507.4) | — | — |
| 4 | 31.3  (11.2) | 33.0  (9.1) | 71.0  (21.0) | 100.1  (17.6) | 242.5 (127.7) | — |
| Adult | 29.5  (12.2) | 27.7  (8.8) | 80.2  (36.5) | 245.6  (76.1) | 377.7 (158.4) | 906 (111.2) |

*n*, 10–18 observations per whitefly stage. Handling time of fourth-instar whiteflies is shown only for fourth instar and adult beetles, and of "pupal" whiteflies only for adult beetles, because of the reluctance of younger instars to feed on these prey stages.

Consumption of prey began as soon as larvae hatched. The mean number of whitefly eggs eaten by larval *D. pusillus* increased during the first three instars (Table 3). Daily consumption of whitefly eggs during third (mean, 149.1; CV, 92.2%), fourth (mean, 178.8, CV, 83.6%), and fifth instars (mean, 135.7; CV, 44.0%) was highly variable, although the mean was similar among the three instars. The instar (third, fourth, or fifth) in which the greatest consumption occurred varied among different beetles. Total egg consumption by third (mean, 339, CV, 86.5%), fourth (mean, 469; CV, 45.9%), and fifth (407, *n* = 1) instars was pooled in Table 3 because of the high variability between daily observations, the similarity of means, and the small number of beetles surviving to complete successive older instars (*n* = 7, 5, and 1, respectively) in this study.

The number of prey consumed per day by adult female *D. pusillus* was highest when fed on eggs and first instars and decreased as size and age of whitefly increased (Table 4). The integer ratio of eggs and first, second, third, and early fourth instars consumed each day on stage-specific diets was 14:12:6:3:1. We assume that this ratio is determined by the biomass available for extraction from each stage of whitefly.

Feeding was sometimes interrupted before the whitefly was completely consumed, nevertheless resulting in death of the whitefly. This occurred most frequently with fourth-instar prey, which required the most time to consume. Because prey were recorded as eaten only if consumption was complete, our studies probably provide a conservative estimate of the mortality of older whitefly instars because of feeding by *D. pusillus*.

In the comparative greenhouse feeding study, beetles were confined to single leaves on live plants containing all stages of whitefly simultaneously. Because beetles fed on some of each stage, the ratio (determined as described above) was used to convert the numbers of whiteflies eaten in these experiments to equivalent numbers of whitefly eggs for comparison with laboratory studies. Based on this conversion, adult beetles in individual leaflet cages consumed 70% of the food eaten in laboratory studies (nine trials with five females).

Adult feeding activity remained high from eclosion until death, although variation from day to day was typically high. The number of whitefly eggs eaten each day was recorded over most of the entire lifespan of five females (range, 39–91 d); for this group, the mean number eaten each day during the first 10 d of adult life was 193.8 (CV, 33.3%), which was comparable with the mean value of 186.1 (CV, 59.6%) during the final 10 d. The number of whiteflies eaten in 1 d was sometimes as high as 4 times the mean value. Individuals observed feeding heavily on one day often consumed relatively little the next.

An estimate of the time allocated to feeding each day was obtained by multiplying the mean handling time with mean daily consumption of each whitefly stage. The resulting values ranged from 1.1 to 3.6 h/d when prey were abundant; therefore, prey handling time should not be expected to be a major limiting factor on predation of whiteflies by *D. pusillus*.

Table 3. Consumption of whitefly eggs during larval development of *D. pusillus*

| | Instar | | | Total |
|---|---|---|---|---|
| | 1 | 2 | 3–5[a] | |
| Mean | 72.4 | 217.4 | 687.7 | 977.5 |
| SD | 40.9 | 184.4 | 168.1 | 196.3 |
| *n* | 16 | 12 | 7 | 7 |

[a] Total consumption during stadia 3, 4, and 5 shown summed because of high variability within and between these instars (see text for discussion of variability).

Table 4. Mean number of *B. tabaci* eggs and immatures consumed per day by *D. pusillus* adult females when fed exclusively on one stage

| Parameter | Stage | | | | |
|---|---|---|---|---|---|
| | Egg | 1 | 2 | 3 | Early 4 |
| Mean | 167.1 | 138.1 | 71.3 | 35.2 | 11.6 |
| SD | 77.0 | 44.9 | 25.4 | 15.8 | 6.4 |

*n* = 5–12 beetles and 44–58 total d observed for each of first, second, and third whitefly instars; 4 beetles feeding for 8 d each on eggs; 10 beetles for a total of 93 d feeding on fourth instars.

**Oviposition by *D. pusillus*.** Mating was required before oviposition occurred. Following mating, 3–5 d elapsed before oviposition began. Beetle eggs were laid singly on their sides on leaf surfaces among whitefly eggs and nymphs. Eggs were sometimes deposited inside whitefly exuviae. In the laboratory, eggs were laid on any solid dry surface, including the sides and lids of petri dishes.

Oviposition by females fed ad lib on whitefly eggs in the laboratory studies averaged $3.0 \pm 0.8$ eggs per day (range, 1.7–4.6; $n = 15$ beetles; oviposition recorded for 8–64 d per individual). Eggs were laid on about two-thirds of the days; daily egg production ranged from 1 to as many as 11. The mean lifetime egg production was $183.2 \pm 88.9$, with a maximum of 385. Although daily oviposition by individual females typically varied widely from day to day (CV, 50.3–159.3% among 12 females), mean daily oviposition was relatively constant throughout life. Of five females for which oviposition was recorded throughout most of their life in the laboratory (range, 42–114 d), mean oviposition was 1.82 eggs per day during the first half of life and 1.67 eggs per day during the second half.

No oviposition occurred in laboratory studies when beetles were fed exclusively on whitefly nymphs, even though they were likely to have fed on eggs before being removed from the laboratory colony for feeding experiments. The number of consecutive days beetles were fed on diets of immatures ranged from 5 to 22 (mean, 8.6).

The number of *B. tabaci* eggs in the diet strongly influenced the fecundity of the beetle (Fig. 1). Beetle reproduction within each diet was consistent over the 9 d of the study. Females consuming ≤100 eggs per day also produced virtually no progeny after being placed on reduced diets ($0.11 \pm 0.52$ on a diet of 50 whitefly eggs per day; $0.13 \pm 0.34$ on a diet of 100 eggs per day). Six of the nine females on the diets with 50 and 100 whitefly eggs per day deposited eggs only on the first day after being placed on the reduced diets; one individual laid a single egg 4 and 5 d into the 100-egg diet. Beetle fecundity increased with whitefly egg consumption ($1.39 \pm 1.57$ on diet of 150 eggs per day; $2.39 \pm 2.11$ on diet of 200 eggs per day). Oviposition by females fed to satiation was higher under greenhouse conditions than in the laboratory, averaging $6.1 \pm 4.03$ eggs per day. These females consumed a mean of $251.4 \pm 61.6$ whitefly eggs per day, 51% more than those eaten in the laboratory study. Mean daily oviposition within each group differed significantly ($P < 0.05$).

When ovipositing beetles fed ad lib in the laboratory on whitefly eggs were placed on reduced diets of 50 whitefly eggs per day, oviposition dropped to zero after 6 d (Fig. 2). Their diets were then increased to 100 eggs per day, result-
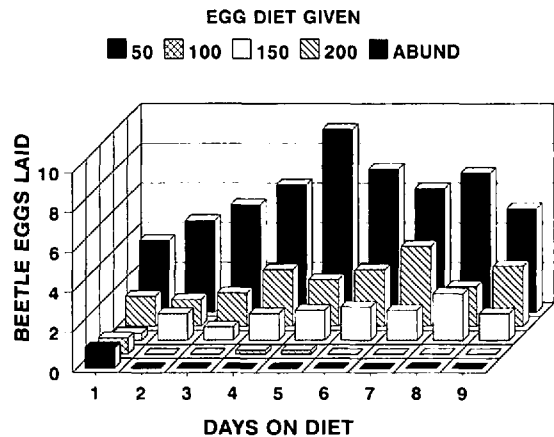
**EGG DIET GIVEN**

■50 ▨100 □150 ▧200 ■ABUND



**Fig. 1.** Mean oviposition of *D. pusillus* consuming different quantities of whitefly eggs. Mated females were fed ad lib. on whitefly eggs until egg production was noted, then placed on one of the following diets: 50, 100, 150, 200, and ≥350 ("abund") whitefly eggs per day ($n = 5, 6, 6, 5, 4$ females completed 9 d on each diet, respectively). Mean number of whitefly eggs actually consumed per day by females on each diet was 50, 100, 133, 171, and 254, respectively.

ing in resumption of an occasional oviposition by a few individuals (3 of 19); most remained unproductive. When diets were increased again to 150 eggs per day, oviposition by beetles increased again to levels at the beginning of the experiment. The mean number of *D. pusillus* eggs laid each day while on the three diets is shown in Table 5. Mean daily oviposition was lowest during the 100 egg per day regime. We assume that oviposition lags behind changes in food intake by as much as several days.
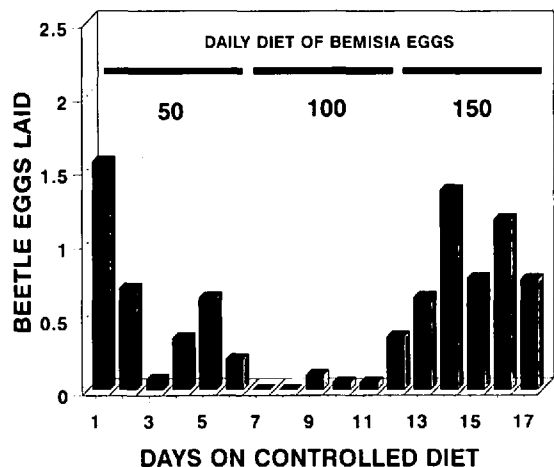


**Fig. 2.** Changes in oviposition by *D. pusillus* in relation to changes in quantity of whitefly eggs in daily diet. Mated females were fed to satiation on whitefly eggs until egg production was noted, then given diets of 50, 100, and 150 whitefly eggs per day sequentially for 5 or 6 d each; $n = 19$ beetles.

Table 5. Mean number of eggs (SD) laid per day by *D. pusillus* fed ad lib. until reproduction, then placed on diets of 50, 100, and 150 eggs per day sequentially for 5 d each

| Diet | Group A[a] | Group B[b] | A + B[c] |
|---|---|---|---|
| 50 eggs/day | 0.79 (0.95)ab | 0.53 (1.08)ab | 0.61 (1.02)b |
| 100 eggs/day | 0.03 (0.08)a | 0.05 (0.12)a | 0.04 (0.11)a |
| 150 eggs/day | 1.09 (0.68)b | 0.76 (0.57)b | 0.87 (0.61)b |

Means within columns followed by different letters are significantly different ($P < 0.05$, REGWF test [Stegner & Bostrom 1984]).

[a] Group A included 6 beetles reared from pupae.

[b] Group B included 13 beetles from lab culture of unknown age and ovipositional history.

[c] Because both groups responded similarly to diets, means for both groups pooled are also given.

These results suggest consumption of between 100 and 150 whitefly eggs per day is required to initiate and maintain *D. pusillus* oviposition. This amount constitutes a large percentage of the average egg consumption by beetles each day when they are given unlimited food in the laboratory, and about half of their consumption in the greenhouse. Because a relatively small part of a beetle's time was spent feeding, even when food was abundant, and searching and handling time was not limiting, the capacity of *D. pusillus* to prey on *B. tabaci* does not appear to extend far beyond the quantity needed to initiate reproduction and reach maximum egg production.

Mixed diets comprising fourth instars and subthreshold levels of 25 or 50 eggs per day for 21 d were not adequate to sustain beetle reproduction. Oviposition was highest when the diet was composed exclusively of eggs (Fig. 3). When beetles were switched from a diet of eggs to fourth instars or were given mixed diets of eggs

**DIET GIVEN**

■4TH  ▨4TH E25  □4TH E50  ■EGG



Fig. 3. Mean daily oviposition by *D. pusillus* reared on four different diets of *B. tabaci*: abundant fourth instars only, 15 fourth instars and 25 eggs, 15 fourth instars and 50 eggs, and abundant eggs only (control); $n = 7$–10 females per diet.
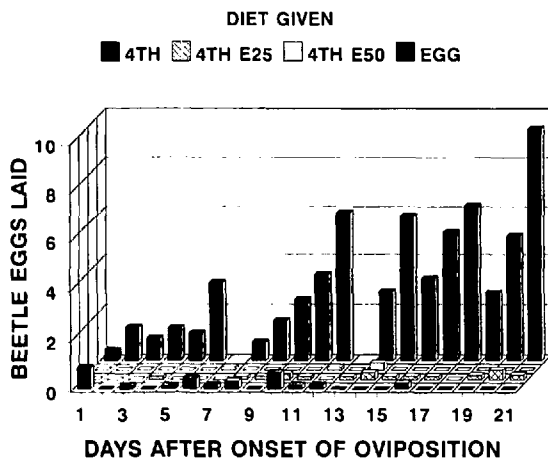
and fourths, only a few eggs were occasionally laid. Two of seven females placed on a diet of fourth instars laid a total of 15 eggs over 21 d; 5 of 15 beetles reared on mixed diets laid a total of 19 eggs over 21 d. No eggs were produced by the remaining beetles on these diets. In contrast, all beetles on the whitefly egg diet produced eggs.

## Discussion

*Delphastus pusillus* is typically found feeding among large populations of whiteflies, usually near the top of the plant among the highest densities of whitefly eggs. Older larvae gradually stop feeding and migrate down the plant in search of protected places to pupate. Pupae are frequently found in aggregations on the undersides of lower leaves. These aggregations are not evenly distributed among all lower leaves but occur only on certain leaves. In the greenhouse, pupation also occurred underneath pots and in other cryptic locations. In greenhouse and insectary culture, *Orius* sp. and various unidentified ants and spiders sometimes preyed upon larval and pupal beetles. Predation of *D. pusillus* was not observed in the field.

When fed on *B. tabaci*, beetles feeding exclusively on abundant whitefly eggs were considerably more fecund than those feeding on lesser quantities of eggs or any other combinations of instars. When diets consisted entirely of whitefly nymphs, no beetle eggs were laid. The composition of diet is known to have a profound influence on egg production by many species of polyphagous coccinellids (Hagen 1962). During the course of our study, we noticed that *D. pusillus* also consumed eggs of *Tetranychus urticae* Koch and *Polyphagotarsonemus latus* (Banks). Some coccinellids are known to feed on honeydew produced by their prey (Hagen 1962), but we did not observe this behavior. However, beetles were observed feeding on diluted honey used in the laboratory as a feeding supplement for parasitoids. Although we did not investigate the influence of alternate foods on the reproduction of *D. pusillus*, such information would be very useful in understanding the field ecology of this predator. We also noticed that *D. pusillus* adults avoided feeding on whitefly nymphs parasitized by *Encarsia transvena* (Timberlake); this tendency was confirmed in further experiments to be described in detail elsewhere.

Species in the coccinellid tribe Serangiini, which includes the genus *Delphastus*, are relatively specific predators of whiteflies. Consequently, they would be expected to be well adapted as natural enemies of whitefly pests. However, there are only a few examples of successful use of predators for biological control of whiteflies. Gerling (1990) suggested that this is because of a relative lack of knowledge of pred-

ator ecology and the difficulty in obtaining data on predator activity in field crops. One documented success involves *Serangium parcesetosum* (Sicard), a coccinellid which has been introduced successfully against citrus whitefly, *Dialeurodes citri* (Ashmead), in Asian Georgia, France, and Corsica (Timofeeva & Hoang Duik Nyuan 1978, Malausa et al. 1988) and has complemented the action of the parasitoid *Encarsia lahorensis* (Howard) (Malausa et al. 1988).

Although *D. pusillus* did not significantly reduce whitefly populations on cassava (Gold & Altieri 1989), it was responsible for a significant proportion of mortality in citrus blackfly populations (Smith et al. 1964, Cherry & Dowell 1979) even though it could not be depended upon to regulate whitefly populations alone. Our results and those of Smith et al. (1964) suggest that it may be most effective under warm and humid conditions. Smith et al. (1964) also noted that *D. pusillus* appeared to be more effective in heavy whitefly populations. The apparent reproductive requirement for a diet high in eggs may explain this observation. Development of immatures also required a large number of whiteflies. Although adults are good fliers and can readily disperse to find prey, larvae are less mobile and are likely to develop to maturity only when beetle eggs are laid among large numbers of prey.

Our studies suggest that *D. pusillus* probably will not maintain itself without augmentation in low or highly dispersed populations of whiteflies. Based upon average consumption of prey and longevity in the laboratory, individual beetles could consume as many as 10,000 whitefly eggs or 700 fourth instars during a lifetime. The beetle's effect on whiteflies under greenhouse conditions could be even higher, although their longevity under these conditions is not known. Because of its capacity to consume large numbers of whiteflies or feed on alternate prey, *D. pusillus* may be of value in helping to manage populations of whitefly in conjunction with other management methods as part of an integrated approach.

## Acknowledgments

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