Reproductive Biology of *Fidiobia dominica* (Hymenoptera: Platygastridae), an Egg Parasitoid of *Diaprepes abbreviatus* (Coleoptera: Curculionidae)

RITA E. DUNCAN,[1] BRYAN J. ULMER,[1] JORGE E. PEÑA,[1,2] AND STEPHEN L. LAPOINTE[3]

ABSTRACT   The reproductive biology of *Fidiobia dominica* Evans (Hymenoptera: Platygastridae) was studied in the laboratory (25.6 ± 1°C) using host eggs of *Diaprepes abbreviatus* L. (Coleoptera: Curculionidae). *F. dominica* readily parasitized *D. abbreviatus* eggs on both host plant and wax paper substrates. The number of egg masses parasitized and the number of offspring produced were higher when females were offered more than one host egg mass but did not differ when either two or three egg masses were offered. Female parasitoids that were provided with host eggs and a honey food source lived significantly longer than those that were not provided a food source; however, they did not parasitize more *D. abbreviatus* eggs. Oviposition occurred in host eggs from 0 to 7 d old, and host mortality was relatively consistent for eggs 0–5 d old and lower for eggs 6–7 d old. Successful parasitoid emergence seldom occurred after host eggs were 4 d old, and by 7 d, no adults successfully emerged. Developmental time from egg to adult was 19.3 ± 0.2 d for males, significantly more rapid than the females (20.4 ± 0.1 d). The mean longevity of adult females was 8.0 ± 0.4 d, with a mean oviposition period of 2.7 ± 0.3 d; males survived 8.1 ± 0.4 d. The demographic parameters including intrinsic rate of increase (r_m), generation time (T), and net reproduction (R_o) were 0.142/d, 22 d, and 22.4 female eggs/d, respectively.

KEY WORDS   classical biological control, citrus integrated pest managment, oviposition, reproduction, nutrition

Diaprepes abbreviatus L. (Coleoptera: Curculionidae) was first reported in the United States in Orange County, FL, in 1964 (Woodruff 1964). It is now established across south and central Florida and is a major pest of the citrus industry, where it is estimated to cost producers tens of millions of dollars annually (Stanley 1996); it is also a significant pest for ornamental growers. *D. abbreviatus* has also established in the Rio Grande Valley of Texas (Skaria and French 2001) and at selected sites in Orange, Los Angeles, and San Diego Counties in California, where it poses a risk to multiple crops (Grafton-Cardwell et al. 2004, Klunk 2005, K. Godfrey, personal communication). The weevil is native to the Lesser Antilles of the Caribbean and was presumably introduced to the United States from Puerto Rico with imported ornamental plants (Woodruff 1985, McCoy and Simpson 1994). *D. abbreviatus* is highly polyphagous and has been associated with plants from 59 families (Simpson et al. 1996). Citrus and various woody ornamentals support the entire life cycle of this insect (Schroeder et al. 1979).

Diaprepes abbreviatus is a relatively large weevil (10–19 mm) that feeds along the edges of leaves,

leaving semicircular notches. Females lay clusters of eggs in the canopy between two leaves that are cemented together with a gelatinous secretion, leaving the egg mass concealed and protected. Adult females survive for ≈150 d and produce ≈5,000 eggs during that time (Wolcott 1936). On hatching, neonate larvae fall to the ground to enter the soil and feed on the roots of host plants. Damage from root feeding can be significant, leading to reduced productivity and possibly death of the host plant. Root feeding may also leave woody host plants such as citrus more susceptible to root rot organisms including *Phytophthora* spp. (Timmer et al. 2005). Citrus production in infested areas has been heavily impacted, resulting in severe tree decline and loss of production (McCoy et al. 1995).

Biological control is a critical element in an ongoing effort to establish an integrated pest management (IPM) system for *D. abbreviatus.* The lack of native parasitoids attacking this pest (Hall et al. 2001) and an earlier failed attempt at classical biological control (Sutton et al. 1972) led to programs aimed at introducing hymenopteran egg parasitoids from the Caribbean. From 1997 to 2000, three species of egg parasitoid were introduced into Florida. *Ceratogramma etiennei* Delvare (Hymenoptera: Trichogrammatidae) was recovered 1 yr after its release but failed to establish (J.E.P., unpublished data). *Quadrastichus haitiensis* Gahan and *Aprostocetus vaquitarum* Wolcott (Hymenoptera: Eulophidae) have established in areas

[1] University of Florida, Department of Entomology and Nematology, Tropical Research and Education Center, 18905 SW 280th St., Homestead, FL 33031.

[2] Corresponding author, e-mail: jepe@ifas.ufl.edu.

[3] U.S. Horticulture Research Laboratory, USDA–ARS, 2001 South Rock Rd., Fort Pierce, FL 34945.

of south Florida, where they cause significant mortality to *D. abbreviatus* eggs (Peña et al. 2006). However, neither parasitoid has established in the citrus-producing areas of central Florida (Castillo et al. 2006, Ulmer et al. 2006). *D. abbreviatus* is established from the southern tip of the peninsula in Miami-Dade County to Marion and Volusia counties in the central portion of the state (Weissling et al. 2004). Consequently, efforts are ongoing to discover an egg parasitoid that will successfully inhabit the range of *D. abbreviatus* in Florida.

In April 2003, J.E.P. led a survey for citrus weevil egg parasitoids on the island of Dominica. *Fidiobia dominica* Evans (Hymenoptera: Platygastridae) was discovered attacking *Diaprepes doublierii* (Guérin) and caused ≈11% mortality (Evans and Peña 2005). It was subsequently imported to the quarantine facility at the University of Florida, Tropical Research and Education Center (UF-TREC), in Homestead, FL, to be studied as a potential biological control agent for *D. abbreviatus.* Preliminary studies showed that *F. dominica* is a primary, solitary endoparasitoid that successfully parasitizes *D. abbreviatus* eggs (Evans and Peña 2005). In this study, we report on the investigations undertaken to determine the reproductive biology of *F. dominica.* Various aspects of reproduction were studied under laboratory conditions using *D. abbreviatus* as a host, including fecundity, developmental time, and the conditions of the host necessary for successful parasitism, as well as the influence of various rearing conditions. The data presented are a critical step toward understanding the basic biology and conditions needed for rearing this previously unstudied insect.

Materials and Methods

Insects. Colonies of *D. abbreviatus* were obtained by collecting adult weevils from fields of ornamental trees near Homestead, FL (80.2° W, 25.3° N, 1 m alt). The weevils were placed in 30 by 30 by 30-cm Plexiglas cages (200 adults per cage) with water and foliage of the host plant *Conocarpus erectus* L. (Myrtales: Combretaceae), which provided a food source and an oviposition substrate. The foliage was in the form of bouquets containing 20–25 terminal branches (each 15–20 cm long and with ≈10 leaves) placed in a 500-ml plastic container full of water. Wax paper strips (3 by 10 cm) stapled together were also used as an oviposition substrate as described by Étienne et al. (1990). The oviposition substrate was renewed every 2–3 d. The stock colony of *D. abbreviatus* was held in a room maintained at 25.6 ± 1°C, 12:12 L:D, and ≈65% RH.

A colony of *F. dominica* was initiated at the UF-TREC from material collected in Dominica (Evans and Peña 2005). The stock colony of *F. dominica* was reared on *D. abbreviatus* host eggs using wax paper as a substrate (Etienne et al. 1990) and was held in a room maintained at 25.6 ± 1°C, 12:12 L:D, and ≈65% RH. Voucher specimens of *F. dominica* were retained by the U.S. National Museum of Natural History (USNM), Florida Collection of Arthropods (Gainesville, FL),

and the Canadian National Collection (Ottawa, Canada).

Assessment of Oviposition Substrates. To establish the oviposition substrate for our assays, *F. dominica* was offered <2-d-old *D. abbreviatus* egg masses (49.8 ± 1.9 eggs per egg mass) either concealed between *C. erectus* leaves as they would occur in nature, exposed on *C. erectus* leaves by separating the leaves of an egg mass, or exposed on wax paper strips. One naive female (<2 d old) was placed into a 10-ml test tube with a single egg mass. A smear of honey was provided on the inner surface of each test tube as a food source, and the open end of the tube was covered with a double ply Kimwipe (Kimwipes EX-L; Kimberly-Clarke, Rosswell, GA) secured with rubber tubing. Twenty-one *F. dominica* females were tested on each of the three treatments in a no-choice situation for a total of 63 insects. Host and parasitoid survival were recorded on each substrate; survival was considered neonate emergence for *D. abbreviatus* and adult emergence for *F. dominica.* In addition, a second set of test tubes was used to assess survival of *D. abbreviatus* eggs on each substrate without *F. dominica* (n = 20). Total number of eggs and neonate emergence were recorded on each substrate.

Host Availability. To determine the number of host egg masses needed to maximize fecundity, an excess number of host eggs were provided to *F. dominica.* Treatments consisted of a female *F. dominica* (0–3 d old) provided with one, two, or three egg masses (<2 d old) of *D. abbreviatus* in 10-ml test tubes as above. Host egg masses on wax paper were offered to each female for 24 h. The number of egg masses parasitized by each female, number of progeny produced by each female, and the number of host eggs available were recorded once all *F. dominica* adults and *D. abbreviatus* neonates emerged. The experiment was repeated 30 times for each treatment. Females that did not oviposit during the 24-h period were not included in the analysis.

Parasitoid Nutrition. To determine the effect of nutrition on female longevity, females were held under one of four conditions: water only; honey only; host eggs and water; or host eggs, water, and honey. Females (<24 h old) were placed in 10-ml glass test tubes (as above). The host egg treatments consisted of two *D. abbreviatus* egg masses (<2 d old) laid on wax paper. Those treatments that did not need host eggs received wax paper blanks with no eggs. Host eggs were removed and replaced daily. Exposed host egg masses were removed and placed in 10-ml glass test tubes (as above) until adult emergence. Emerging parasitoids were counted and sexed. Honey was provided in the form of a smear created with the pointed end of a needle on the inner surface of the test tube. Water was provided by wetting the double ply Kimwipe that covered the open end of the test tube. Females were checked twice daily for survival. The experiment was repeated with 28–30 females for each treatment.

Influence of Host Egg Age on Parasitism. A no-choice test was conducted to study *F. dominica* host

Table 1. Mean number (±SE) of total *D. abbreviatus* eggs, neonates, dead eggs, *F. dominica* adults, and parasitized eggs that did not produce adult *F. dominica* on three different oviposition substrates including wax paper, open *C. erectus*, and closed *C. erectus*

Treatment	Total Da eggs	*D. abbreviatus* neonates	*D. abbreviatus* eggs dead	Dead parasitized eggs	*F. dominica* adults
Wax paper	58.1 (4.2) a	29.7 (5.2) ab	2.7 (1.8) a	7.5 (2.9) ab	18.3 (3.5) a
Open *C. erectus*	46.3 (4.2) a	17.3 (3.3) b	3.6 (1.7) a	9.6 (2.8) a	15.8 (3.4) a
Closed *C. erectus*	47.4 (4.9) a	41.1 (5.3) a	0.2 (0.2) a	1.1 (0.4) b	5.0 (1.0) b

Means within each column followed by the same letter are not significantly different ($P = 0.05$).

egg age preference. *D. abbreviatus* egg masses 1–7 d old were exposed to *F. dominica* females on wax paper. Host eggs were held in a 10-ml glass test tube (as above) before exposure to *F. dominica.* When eggs reached the appropriate age (1–7 d old), a single *D. abbreviatus* egg mass (58.1 ± 4.2 eggs) was offered to a naive mated female (0–2 d old) for 24 h. After 24 h, the female was removed, and the egg mass was held in a 10-ml test tube until all *F. dominica* adults and *D. abbreviatus* neonates had emerged. The number of host eggs per egg mass, the number and sex of the emerging parasitoids, and the number of dead *D. abbreviatus* eggs were recorded. The experiment was replicated 29 times with host eggs aged 1, 2, 3, 4, 5, and 6 d and 22 times for 7-d-old eggs.

Developmental Time. Developmental time of male and female *F. dominica* was determined by offering two host egg masses (<2 d old) on wax paper to individual females ($n = 25$) held in 10-ml test tubes as above. Host egg masses were exposed to the females for 24 h; egg masses were individually transferred to 10-ml test tubes. Each egg mass was inspected daily for parasitoid emergence. Emerging parasitoids were recorded daily and removed and sexed at the time of emergence.

Fecundity, Adult Longevity, and Demographic Parameters. To determine daily and overall fecundity of *F. dominica*, presumably mated females <2 h old were placed in 10-ml test tubes (as above) with two host egg masses (<2 d old) on wax paper. Host egg masses were replaced by new ones daily until the female died. Host eggs were held until all *F. dominica* adults and host neonates emerged. These results were combined with developmental times and the sex ratio obtained in the earlier experiments to construct a life table for *F. dominica* and to calculate its intrinsic rate of increase (r_m), generation time (T), and net reproduction (R_o) (Birch 1948, Southwood and Henderson 2000). The following equations were used: $Ro = \Sigma lxmx$, $T = \Sigma xlxmx/R_o$, r_m estimation $= \Sigma explxmx(-r_mx) = 1$, where lx is the survivorship of the original cohort at age x, and mx is the number of female offspring produced per surviving female in each age interval.

Experimental Conditions and Statistical Analysis. All experiments were conducted in a room maintained at 25.6 ± 1°C, 12:12 L:D, and ≈65% RH. For assessment of oviposition substrates, parasitoid nutrition, and host availability, means were compared by Tukey's honestly significant differences (HSD) test after a significant analysis of variance (ANOVA; $P < 0.05$). To examine the effect of host egg age on parasitoid emer-

gence and host mortality and detect significant differences between the means ($P < 0.05$), data were subjected to a Kruskal-Wallis ANOVA. A one-way ANOVA was performed to determine differences in developmental time and adult longevity between the sexes of *F. dominica* (Statistix 8; Analytical Software 2003).

Results

Assessment of Oviposition Substrates. The initial number of *D. abbreviatus* eggs offered on the three oviposition substrates was not significantly different ($F_{2,60} = 2.16$, $P = 0.12$; Table 1). The number of *D. abbreviatus* eggs that died from causes other than parasitism was also not significantly different ($F_{2,60} = 1.45$, $P = 0.24$). *F. dominica* females parasitized substantially more host eggs on open wax paper and open *C. erectus* than they did on closed *C. erectus.* Significantly more progeny were produced ($F_{2,60} = 6.12$, $P = 0.004$) and more host eggs were killed without adult emergence ($F_{2,60} = 3.72$, $P = 0.03$) on wax paper and open *C. erectus* than on closed *C. erectus.* Consequently, more neonate *D. abbreviatus* emerged from closed *C. erectus* than from the other oviposition substrates ($F_{2,60} = 6.49$, $P = 0.003$). In the control where eggs were not exposed to *F. dominica* females, there was no difference in mean egg mortality on wax paper (2.5 ± 1.4 SE), open (1.3 ± 1.1), or closed (0.3 ± 0.1) *C. erectus* ($F_{2,57} = 1.11$, $P = 0.34$).

Host Availability. The mean number of egg masses parasitized was significantly higher when females were offered more than one egg mass, and the mean number of egg masses parasitized did not differ for females offered either two or three host egg masses ($F_{2,83} = 24.6$, $P < 0.001$; Table 2). Ninety-seven percent of the tested females oviposited; females that did not oviposit were not included in the analysis. The mean number of eggs parasitized by *F. dominica* was significantly higher when offered more than one host egg mass, but there was no significant difference between those females offered two or three egg masses ($F_{2,29} = 4.0$, $P = 0.02$). Females produced ≈15% more offspring when offered more than one egg mass. Females parasitized 74% of host eggs when offered a single egg mass. This proportion was significantly reduced when the number of egg masses was increased ($F_{2,83} = 39.0$, $P < 0.001$; Table 2).

Parasitoid Nutrition. Female longevity was significantly affected by an oviposition substrate and a source of nutrition. Females that were provided with

Table 2. Mean number (±SE) of egg masses and individual eggs parasitized by *F. dominica* when offered one, two, or three host *D. abbreviatus* host egg masses

Number of egg masses offered	n	Host egg masses parasitized per female	Host eggs parasitized per female	Proportion of host eggs parasitized	Percent of host egg masses parasitized
1	29	1.00 ± 0.00 b	31.14 ± 2.11 b	0.74 ± 0.04 a	100
2	29	1.72 ± 0.08 a	36.14 ± 1.19 a	0.46 ± 0.03 b	86.2
3	28	1.79 ± 0.13 a	37.14 ± 1.36 a	0.34 ± 0.02 c	59.5

Means within each column followed by the same letter are not significantly different *(P = 0.05)*. The mean number of host eggs per egg mass included in this study was 40.85 ± 1.36.

only host eggs and water died earlier than those provided host eggs and honey or honey and no host eggs ($F_{3,110} = 20.1$, $P < 0.001$; Table 3). Females provided only honey had the longest adult lives, which were approximately four times longer than those provided eggs and water. The presence of water did not affect longevity when females were provided with honey. Although females lived longer when provided a honey food source, they did not parasitize significantly more *D. abbreviatus* eggs than females that were not provided a food source ($F_{1,56} = 1.13$, $P = 0.29$). The number of adult offspring produced was also not significantly different between the treatments ($F_{1,56} = 0.56$, $P = 0.45$); the sex ratio of the offspring was comparable on the two treatments (Table 3).

Influence of Host Egg Age on Parasitism. Successful development of *F. dominica* to adult emergence occurred more frequently from the youngest host eggs (Table 4). The number of *F. dominica* emerging as adults decreased with increasing age of *D. abbreviatus* eggs. After 4 d, significantly fewer *F. dominica* were able to complete development, and by 7 d, no adults successfully emerged ($F_{6,189} = 19.1$, $P < 0.001$; Table 4). Consequently, significantly more females ($F_{6,189} = 16.1$, $P < 0.001$) and males ($F_{6,189} = 11.3$, $P < 0.001$) emerged from younger host eggs. Overall, host *D. abbreviatus* egg mortality was relatively consistent for eggs from 0 to 5 d old but was significantly lower for eggs 6–7 d old ($F_{6,189} = 6.81$, $P < 0.001$). *F. dominica* females attacked host eggs of all ages; generally the younger the host eggs, the further along parasitoid progeny developed. In 1-d-old host eggs, the majority of parasitized eggs successfully emerged. Those that did not emerge as adults generally reached the pupal stage. On host eggs >3 d old, the majority of parasit-

ized eggs did not successfully emerge, and many of those did not even reach pupation. Host eggs that were 7 d old did not seem to support parasitoid development past the egg or early instars. There was no significant difference in the number of host eggs that were offered to females for the different host age groups ($F_{6,189} = 1.88$, $P = 0.09$). The sex ratio of *F. dominica* emerging from host eggs of different ages was relatively consistent across all host egg ages.

Developmental Time. A total of 41 male and 362 female *F. dominica* offspring emerged from the egg masses offered to 25 ovipositing females. Male developmental time from egg to adult was significantly shorter than that of females ($F_{1,401} = 35.0$, $P = <0.001$). Males emerged 19.3 ± 0.2 d after oviposition, ≈1 d earlier than females, which emerged 20.4 ± 0.1 d after oviposition.

Fecundity, Adult Longevity, and Demographic Parameters. Oviposition began on the first day after emergence for 64% of the *F. dominica* females tested. The mean oviposition period was 2.7 ± 0.3 d, about one half as long as the postoviposition period, which was 4.7 ± 0.5 d. Fifty-two percent of a female's lifetime progeny production resulted from eggs laid the first day after emergence, and 87% of progeny were produced by the end of the second day of a female's life (Fig. 1). Only 3% of the offspring resulted from eggs laid after the fourth day of adult life. The sex ratio of the offspring was not affected by the age of the adult female. The mean longevity of adult female *F. dominica* was 8.0 ± 0.4 d, with a range of 5–11 d, and adult males survived 8.1 ± 0.4 d with a range of 5–13 d; the difference in adult longevity was not significant ($F_{1,48} = 0.02$, $P = 0.89$). The demographic parameters are given in Table 5.

Table 3. Mean number of days adult females survived with and without host eggs and sources of nutrition and water

Treatment	Longevity (d)	Adult offspring	Total parasitism	Proportion female
Eggs/water	2.6 (0.2) b	13.2 (2.4) a	25.1 (2.5) a	0.76
Eggs/honey/water	7.7 (0.7) a	15.8 (2.4) a	28.7 (2.3) a	0.79
Honey/water	8.6 (0.7) a			
Honey	10.3 (1.1) a			

Means within each column followed by the same letter are not significantly different *(P = 0.05)*. Mean number of host eggs parasitized, total offspring produced, and proportion female offspring when females were provided host eggs with and without a nutrition source.

Discussion

Fidiobia dominica was reared effectively on *D. abbreviatus* host eggs. This parasitoid was discovered on the island of Dominica attacking *Diaprepes doublierii* (Evans and Peña 2005); however, it thrived on *D. abbreviatus* host eggs in the laboratory and seems to be a viable biological control agent against this pest. Females oviposited under all conditions tested, but laboratory parasitism rates and adult production were higher when the host egg masses were opened and exposed to the parasitoid. Host eggs exposed on plant material and wax paper strips (Etienne et al. 1990) produced approximately the same amount of *F. do-*

Table 4. Mean (±SE) *F. dominica* (Fd) parasitism and resulting mortality of *D. abbreviatus* (Da) eggs from 1 to 7 d old

Host egg age (d)	n	Fd adults emerged	Fd females	Fd males	Dead Da eggs	Total Da mortality	No. of Da eggs/mass
0–1	29	18.8 (2.4) a	16.1 (2.3) a	2.7 (0.8) a	9.6 (2.1) a	28.5 (1.8) a	41.5 (1.9) a
1–2	29	11.3 (2.2) ab	10.1 (2.0) ab	1.2 (0.3) ab	14.3 (1.9) ab	25.6 (1.7) a	40.4 (2.7) a
2–3	29	12.7 (2.1) ab	8.3 (1.9) ab	3.4 (1.2) ab	9.9 (1.7) a	22.6 (2.1) a	36.3 (1.9) a
3–4	29	8.4 (1.9) ab	7.4 (1.7) ab	1.0 (0.3) abc	18.6 (2.5) ab	27.1 (2.7) a	41.4 (1.9) a
4–5	29	3.8 (1.9) bc	3.4 (1.2) bc	0.4 (0.2) bc	22.5 (2.4) b	26.3 (2.4) a	43.2 (1.4) a
5–6	29	0.1 (0.1) c	0.1 (0.1) c	0.0 (0.0) c	19.2 (2.3) ab	19.2 (2.4) ab	39.0 (2.2) a
6–7	22	0.0 (0.0) c	0.0 (0.0) c	0.0 (0.0) c	9.2 (2.0) a	9.2 (2.0) ab	42.6 (2.0) a

Means within each column followed by the same letter are not significantly different ($P = 0.05$).

minica offspring. Given that rearing this insect with wax paper was much less labor intensive, it was the preferred method for colony production and assay design. To maximize *F. dominica* production, the number of host egg masses offered should be approximately two per female each of the first 2–3 d of adult life; however, production does not increase by offering females more than two host egg masses of average size. It is noteworthy that, when females were presented with more than one host egg mass, they would often attack eggs from additional egg masses without parasitizing 100% of the eggs in any one egg mass.

A carbohydrate source of nutrition has been shown to increase adult longevity, and often reproductive parameters, for many hymenopteran parasitoids (Heimpel et al. 1997, Baggen and Gurr 1998, Wäckers 2001, Olson et al. 2005, Williams et al. 2005). *Fidiobia dominica* females that were fed honey lived longer than those without; however, honey did not increase fecundity under laboratory conditions. Oviposition in both treatments was limited almost entirely to the first 2 d. It seems that *F. dominica* females have a finite number of eggs, and given the minimal effort needed to locate hosts under laboratory conditions, they were able to oviposit these eggs within the first 2–3 d after emergence, regardless of the food resource provided. Leatemia et al. (1995) reported that, although lifetime offspring production of *Trichogramma minutum* Riley (Hymenoptera: Trichogrammatidae) was significantly higher when offered a honey food source, offspring production in the first 2 d was not significantly different for females provided honey compared with those that were unfed. Although a food source may not

be vital for colony production, it may be much more important under field conditions where females would be required to forage and expend much more energy and time to locate host eggs. Some host eggs were killed with no parasitoid development in each treatment, but it was not clear if these eggs were fed on by female *F. dominica.* Host feeding by females has been observed in other parasitoids and is assumed to provide female wasps with resources that can be used during host searching or for egg maturation (Jervis and Kidd 1986, Godfray 1994).

Fidiobia dominica attacked host eggs from 0 to 7 d old; however, successful development to the adult stage dropped significantly when host eggs reached an age of 4–5 d. Although parasitoid development was generally not successful on host eggs that were >4 d old, the host egg was killed, resulting in substantial *D. abbreviatus* mortality among all ages of host eggs exposed to this parasitoid. Development of *D. abbreviatus* seemed to cease when parasitoid oviposition occurred, but it was not clear if the host was killed by the ovipositing female or the developing parasitoid. The relationship between host age and parasitoid oviposition and development observed for *F. dominica* was very similar to that observed for two other *D. abbreviatus* egg parasitoids: *A. vaquitarum* and *Q. haitiensis* (Jacas et al. 2005, Castillo et al. 2006). These eulophid parasitoids attacked host eggs up to 6 and 7 d old, respectively, but, as with *F. dominica*, successful development to the pupal and adult stage dropped significantly after host eggs reached 4 d of age.

Fidiobia dominica females were most productive during the first 2 d of adult life. After 2 d, they laid very few eggs, and no eggs were laid after the first week. This is in contrast to the eulophid egg parasitoids *A. vaquitarum* and *Q. haitiensis*, both of which laid a substantial number of eggs the first week of adult life and continued at low levels of oviposition for 2 wk at the same temperature (Jacas
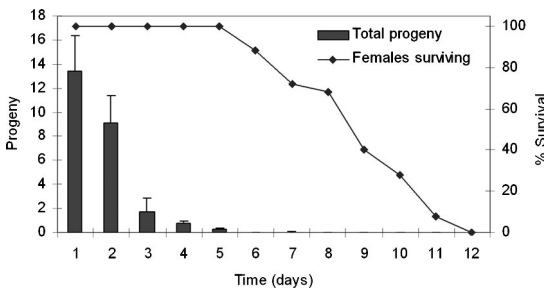

Fig. 1. Mean survival and mean (±SE) number of progeny (emergent adults) produced by female *F. dominica* on each day of adult life when provided honey and an excess of host eggs.

Table 5. Demographic parameters of *F. dominica* reared in the laboratory on *D. abbreviatus*

Temperature	R_o	T	r_m
26.5°C	22.4	22.0	0.142

Net reproductive rate (R_o = female replacement), mean generation time (T, d), and intrinsic rate of increase (r_m, d^{-1}).

et al. 2005, Castillo et al. 2006). Female longevity was also substantially lower for *F. dominica* (8.0 d) than was reported for either *A. vaquitarum* (15.2 d) or *Q. haitiensis* (14.5 d). Given the relatively brief life span and oviposition period of *F. dominica*, host availability, in time and space, may be more crucial for the establishment of this parasitoid. However, the demographic parameters for *F. dominica* are comparable with those of *A. vaquitarum* and *Q. haitiensis* (Jacas et al. 2005, Castillo et al. 2006), which have been successful egg parasitoids of *D. abbreviatus* in south Florida (Peña et al. 2006).

Overall, the demographic parameters for *F. dominica* reared on *D. abbreviatus* in the laboratory and its affinity for this host make it a promising candidate for biological control of this invasive pest. The development of a colony production protocol and the success of this parasitoid in the laboratory is also encouraging and bodes well for the planned release of *F. dominica* in Florida. Further research is needed to understand the effect of environmental factors, such as temperature and humidity, on population establishment and dispersal in the field.

Acknowledgments

References Cited

Baggen, L. R., and G. M. Gurr. 1998. The influence of food on *Copidosoma koehleri* (Hymenoptera: Encyrtidae), and the use of flowering plants as a habitat management tool to enhance biological control of potato moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae). Biol. Control 11: 9–17.

Birch, L. C. 1948. The intrinsic rate of natural increase of an insect population. J. Anim. Ecol. 17: 15–26.

Castillo, J., J. A. Jacas, J. E. Peña, B. J. Ulmer, and D. G. Hall. 2006. Effect of temperature on life history of *Quadrastichus haitiensis* (Hymenoptera: Eulophidae), an endoparasitoid of *Diaprepes abbreviatus* (Coleoptera: Curculionidae). Biol. Control 36: 189–196.

Étienne, J., H. Mauléon, and B. Pinturau. 1990. Biologie et dynamique de *Ceratogramma etiennei* (Hymenoptera: Trichogrammatidae) parasite de *Diaprepes abbreviatus* (L.) (Coleoptera: Curculionidae) en Guadeloupe. Les Colloques. INRA. 58: 459–68.

Evans, G. A., and J. E. Peña. 2005. A new *Fidiobia* species (Hymenoptera: Platygastridae) reared from eggs of *Diaprepes doublierii* (Coleoptera: Curculionidae) from Dominica. Fla. Entomol. 88: 61–66.

Godfray, H.C.J. 1994. Parasitoids: behavioral and evolutionary ecology. Princeton University Press, Princeton, NJ.

Grafton-Cardwell, E .E., K. E. Godfrey, J. E. Peña, C. W. McCoy, and R. F. Luck. 2004. Diaprepes root weevil. University of California, Division of Agriculture and Natural Resources, Oakland, CA.

Hall, D. G., J. E. Peña, R. Franqui, R. Nguyen, P. Stansly, C. W. McCoy, S. Lapointe, R. A. Adair, and B. Bullock. 2001. Status of biological control by egg parasitoids of *Diaprepes abbreviatus* (Coleoptera: Curculionidae) in citrus in Florida and Puerto Rico. Biocontrol 46: 61–70.

Heimpel, G. E., J. A. Rosenheim, and D. Kattari. 1997. Adult feeding and lifetime reproductive success in the parasitoid *Aphytis melinus*. Entomol. Exp. Appl. 83: 305–315.

Jacas, J. A., J. E. Peña, and R. E. Duncan. 2005. Successful oviposition and reproductive biology of *Aprostocetus vaquitarum* (Hymenoptera: Eulophidae): A predator of *Diaprepes abbreviatus* (Coleoptera: Curculionidae). Biol. Control 33: 352–359.

Jervis, M. A., and N.A.C. Kidd. 1986. Host-feeding strategies in hymenopteran parasitoids. Biol. Rev. 61: 395–434.

Klunk, S. 2005. Invasive root weevil spreads to southern California (http://www.citrusresearch.com/frameset.html).

Leatemia, J. A., J. E. Laing, and J. E. Corrigan. 1995. Effects of adult nutrition on longevity, fecundity, and offspring sex ratio of *Trichogramma minutum* Riley (Hymenoptera: Trichogrammatidae). Can. Entomol. 127: 245–254.

McCoy, C. W., and S. E. Simpson. 1994. Past and current IPM strategies to combat the spread of *Diaprepes abbreviatus* in Florida citrus. Proc. Caribbean Food Soc. St. Thomas. 30: 247–255.

McCoy, C. W., E. D. Quintela, and S. E. Simpson. 1995. Effect of surface-applied and soil-incorporated insecticides for the control of neonate larvae of *Diaprepes abbreviatus* in container-grown citrus. Proc. Fla. State Hort. Soc. 108: 130–136.

Olson, D. M., W. J. Lewis, and K. Takasu. 2005. Interactive-web of factors governing effective natural enemy foraging behavior: overview of food resources as a critical component. Proceedings of the International Symposium on Biological Control of Arthropods, 12–16 September 2005, Davos, Switzerland.

Peña, J. E., B. J. Ulmer, J. A. Jacas, R. E. Duncan and C. W. McCoy. 2006. Biological control of Neotropical citrus root weevils. Memorias de la IV Congreso Internacional de Control Biologico, 31 May to 2 June 2006, Palmira, Colombia.

Schroeder, W. J., R. A. Hamlen, and J. B. Beavers. 1979. Survival of *Diaprepes abbreviatus* larvae on selected native and ornamental Florida plants. Fla. Entomol. 62: 309–312.

Simpson, S. E., H. N. Nigg, N. C. Coile, and R. A. Adair. 1996. *Diaprepes abbreviatus* (Coleoptera: Curculionidae): host plant associations. Environ. Entomol. 25: 333–349.

Skaria, M., and J. V. French. 2001. *Phytophthora* disease of citrus associated with root weevils in Texas. Phytopathology 91 (suppl): S203.

Southwood, T.R.E., and P. A. Henderson. 2000. Ecological methods, 3rd ed. Blackwell. Oxford, UK.

Stanley, D. 1996. Suppressing a serious citrus pest. Agric. Res. 44: 22.

Statistix Analytical Software. 2003. Statistix 8 user's manual. Statistix Analytical Software, Tallahassee, FL.

Sutton, R. A., A. G. Selhime, and W. McCloud. 1972. Colonization and release of *Tetrastichus haitiensis* as a biological control agent for citrus root weevils. J. Econ. Entomol. 65: 184–185.

Timmer, L. W., M. E. Rogers, and R. S. Buker. 2005. Florida citrus pest management guide (http://edis.ifas.ufl.edu).

Ulmer, B. J., J. A. Jacas, J. E. Peña, R. E. Duncan, and J. Castillo. 2006. Effect of temperature on life history of *Aprostocetus vaquitarum* (Hymenoptera: Eulophidae), an ectoparasitoid of *Diaprepes abbreviatus* (Coleoptera: Curculionidae). Biol. Control 39: 19–25.

Wäckers, F. L. 2001. A comparison of nectar-and honeydew sugars with respect to their utilization by the hymenopteran parasitoid *Cotesia glomerata.* J. Insect. Physiol. 47: 1077–1084.

Weissling, T., J. E. Peña, R. Giblin-Davis, and J. Knapp. 2004. Diaprepes root weevil (http://creatures.ifas.ufl.edu/citrus/sugarcane_rootstock_borer_weevil.htm).

Williams, L., T. M. Roane, and J. P. Beach. 2005. Gustatory acceptance, longevity, and utilization of nectar and honeydew sugars by *Anaphes iole*, and egg parasitoid of *Lygus* bugs. Proceedings of the International Symposium on Biological Control of Arthropods, 12–16 September 2005, Davos, Switzerland.

Wolcott, G. N. 1936. The life history of *Diaprepes abbreviatus* at Río Piedras, Puerto Rico. J. Agric. Univ. Puerto Rico 20: 883–914.

Woodruff, R. E. 1964. A Puerto Rican weevil new to the United States (Coleoptera: Curculionidae). Florida. Dep. Agr., Div. Plant Ind, Entomol. Circ. 30: 1–2.

Woodruff, R. E. 1985. Citrus weevils in Florida and the West Indies: preliminary report on systematics, biology, and distribution (Coleoptera: Curculionidae). Fla. Entomol. 68: 370–379.