Reproduction, Longevity, and Survival of *Cactoblastis cactorum* (Lepidoptera: Pyralidae)

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ABSTRACT Screened potted cactus, *Opuntia ficus-indica* (L.) Mill., plants containing pairs of adult male and female cactus moths, *Cactoblastis cactorum* (Berg) (Lepidoptera: Pyralidae), were placed in a cactus field in St. Marks, FL, to measure oviposition patterns under ambient conditions. Results showed a narrow window for oviposition during third and sixth day of adult female's life. Peak oviposition activity occurred on the third day, whether measured in total fecundity, numbers of eggs per egg stick or numbers of ovipositions. After the third day, not only did oviposition rate decrease but also the quality of eggs produced declined. Percentage of egg hatch decreased and egg incubation increased. Longevity of adult males (6.3 ± 0.79 d) did not differ from that of females (5.2 ± 0.4), although female adults (157.8 ± 4.5 mg) weighed more than males (74.9 ± 1.51). Therefore, from the perspective of mass rearing this moth, the optimal time for collecting eggs is limited to the third day in the life of the adult female.

KEY WORDS *Opuntia ficus-indica*, egg production, adult body weights, egg incubation

The cactus moth, *Cactoblastis cactorum* (Berg) (Lepidoptera: Pyralidae), has become a textbook example of both successful classical biological control as well as the perils associated with unintentional consequences of biological control agents (Raghu and Walton 2007). *C. cactorum* was exported from Argentina to Australia in 1926 to control invasive *Opuntia* cacti at a cost estimated to be $700 million (adjusted for inflation; Raghu and Walton 2007). However, the value of agricultural land returned to productivity within 5 yr was 42 times the investment, thereby justifying the expenditure. To date, the moth continues to play an active role in controlling *Opuntia* spp. in Australia. The first documentation of invasion into North America occurred in the Florida Keys in October 1989 (Habeck and Bennett 1990). Since then, the moth has progressively expanded its geographical distribution (Hight et al. 2002). In 2005, distribution limits of the cactus moth were as far north as Bull Island, south Carolina on the Atlantic Coast, and as far west as Dauphin Island, AL, on the Gulf Coast (Bloem et al. 2007).

The cactus moth is known to attack 79 species of prickly pear cactus: 51 endemic to Mexico, nine endemic to the Unites States, and 19 common to both countries (Zimmermann et al. 2000). In the United States, *C. cactorum* threatens the cactus industry in Arizona, California, Nevada, New Mexico, and Texas, where cacti are grown primarily as ornamentals. Nursery production is highest in Arizona (wholesale and retail values of $4.5 million and $9.5 million, respectively), followed by southern California (Irish 2001). With its arrival into North America, the moth was identified as a significant threat to the valuable cactus industry of Mexico (Perez-Sandi 2001, Vigueras and Portillo 2001). More than 250,000 ha are cultivated to cactus, producing annual economic revenue of ≈$50 million (1990–1998) (Soberón et al. 2001). Despite attempts to prevent dispersal into Mexico, *Cactoblastis* was found in Isla Mujeres in August 2006. The method by which *C. cactorum* migrated into Mexico is unknown, although speculation centers on winds and hurricanes, or accidental transport via tourists or commercial trade. There is no known effective control method against *C. cactorum*, although significant research has been conducted on the use of sterile insect technique (SIT) methods (Hight et al. 2005).

Here, we studied the reproductive biology of *C. cactorum* in Florida by using field cage experiments.

Materials and Methods

The experiment was conducted near the picnic pond at St. Marks National Wildlife Refuge, St. Marks, FL (30.16–30° 1′ N, −84.21–84° 1′ W) from July to August 2007. Twenty-five plastic pots (15.2 cm in di-

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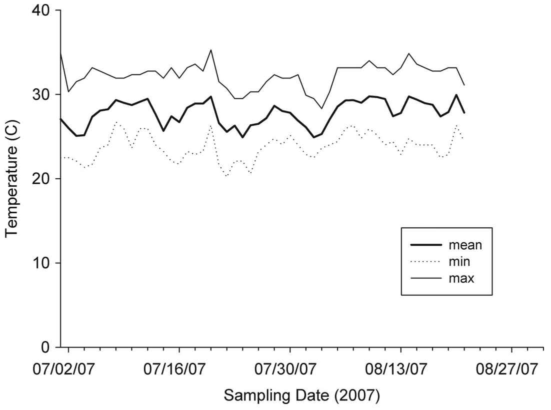

Fig. 1. Mean, maximal, and minimal temperatures at St. Marks, FL, during sampling period (July–August 2007).

ameter) were prepared by placing commercial potting soil mixture and two cactus, *Opuntia ficus-indica* (L.) Mill., pads in each pot. Two wire stakes (25.4 cm in height) and an embroidery ring on top of the stakes (25.4 cm in diameter) were used to hold up an organza screen net to cover each pot. The screen net was secured with a rubber band around the pot. Each covered pot was considered a replicate, for a total of 25 replicates. The potted plants were placed on a 1.8-m-long table. A plastic container filled with water was placed under each leg of the table to prevent ants and other arthropods from entering the screened pots. The plastic containers were filled with water daily or as needed. The screened pots were secured with a wire rope to prevent them from toppling over. A HOBO weather recorder (Onset Computer Corp., Bourne, MA) was placed outside the potted cages at a height of 1.2 m to record daily maximal, minimal, and average temperature (Celsius) readings during the duration of the experiment.

Newly emerged male and female adult moths were collected from a laboratory colony reared at USDA–ARS CMAVE/FAMU-CBC in Tallahassee, FL. At the start of the experiment, one male was paired with one female adult moth in each screened pot. The pots were checked daily for egg sticks until both male and female were dead. Each egg stick laid was collected daily and placed individually in plastic cups (30 ml) covered with a cardboard lid (Solo, Inc., Highland Park, IL). All egg sticks were returned to the laboratory and placed in a growth chamber (Thermoforma, Marietta, OH) at 26°C with a photoperiod of 14:10 (L:D) h and 50 ± 10% RH until eggs hatched. Longevity of adult males and females was measured by recording the number of days they were alive. Fecundity was measured by recording the numbers of ovipositions and eggs per egg stick laid per female. Percentage of eggs that hatched and egg incubation period were measured by recording the numbers of eggs that hatched and the dates the eggs were laid and hatched, respectively.

Statistical Analysis. Total numbers of eggs laid, numbers of eggs per egg stick, percentage of egg hatch, and egg developmental time (duration from egg laying to egg hatch) were analyzed using one-way analysis of variance (ANOVA) with parental age as the independent variable. When *F* values were significant, means were separated using Tukey's honestly significant difference (HSD) test ($P < 0.05$). Arcsine transformation was performed on percentage of egg hatch, but means are presented as nontransformed data (Sokal and Rohlf 1995). Females that did not lay any eggs during their lifetime were removed from the analyses. Time points where no eggs were laid by any females were also excluded from the analyses. All statistical analyses were performed using Systat 12 (Systat Software, Inc., Chicago, IL).

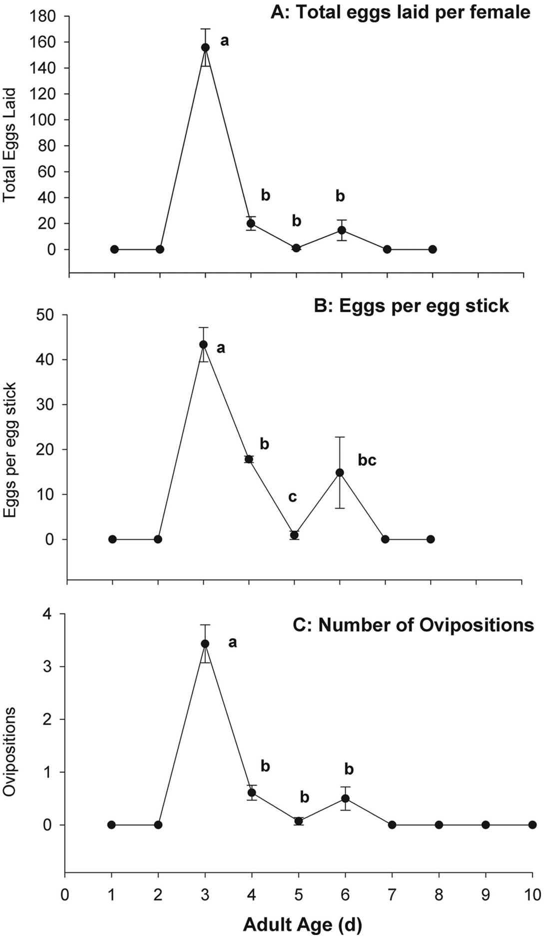

Fig. 2. Effects of age of *C. cactorum* adult females on daily fecundity rate (A), eggs per egg stick (B), and number of ovipositions (C). Data are means ± SE. Different letters beside the mean indicate significant differences among means ($P < 0.05$; Tukey's HSD).

Results and Discussion

Recorded mean, maximal, and minimal temperatures during the sampling period from July to August 2007 are shown in Fig. 1. As typical for the region and

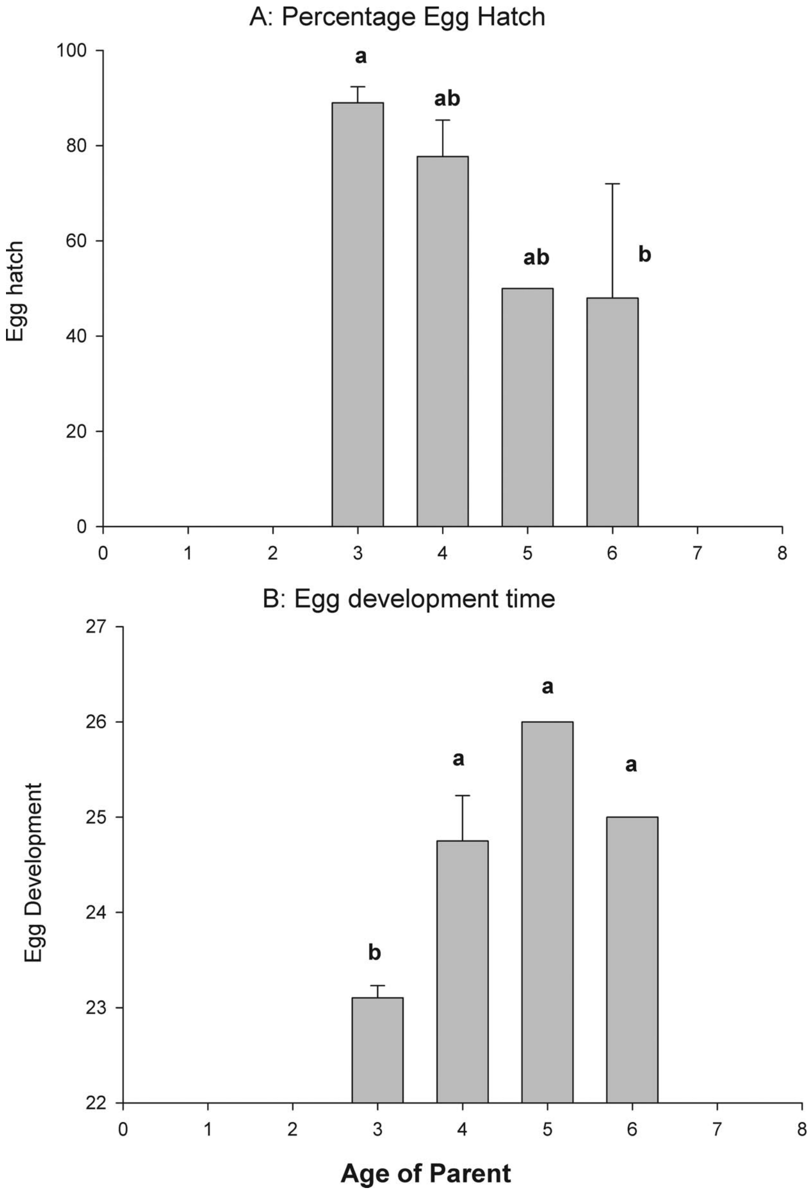

Fig. 3. Effect of age of *C. cactorum* females on percentage of egg hatch (A) and egg developmental time (B). Data are means ± SE. Bars with different letters are significantly different ($P < 0.05$; Tukey's HSD). Percentage of egg hatch shows nontransformed means; data were analyzed using arcsine transformation. Egg developmental time refers to time between eggs being laid and hatching.

time of year, mean temperatures were high (27.8 ± 0.2°C). Four females did not lay any eggs during their lifetimes and were excluded from the analyses (n ♀♀ = 21). One male was lost (n ♂♂ = 24). Because oviposition occurred only in adult females aged 3–6 d, all other times were excluded from the statistical analyses. Total number of eggs laid was significantly highest on day 3 ($F = 49.54$; df = 3, 53; $R^2 = 0.86$; $P < 0.01$) ($P < 0.05$; Tukey's HSD) (Fig. 2A). Numbers of eggs per egg stick also differed with parental age ($F = 17.56$; df = 3, 55; $R^2 = 0.70$; $P < 0.01$) (Fig. 2B). Numbers of eggs per egg stick was highest on day 3, followed by day 4 ($P < 0.05$; Tukey's HSD). Numbers of ovipositions per day was affected by parental age ($F = 36.43$; df = 3, 55; $R^2 = 0.82$; $P < 0.01$) and was highest in 3-d-old adults ($P < 0.01$; Tukey's HSD) (Fig. 2C). Percentage of egg hatch (arcsine transformation) declined with parental age ($F = 3.41$; df = 3, 83; $R^2 = 0.33$; $P < 0.05$) (Fig. 3A). Developmental time to egg hatch tended to increase with parental age ($F = 15.68$; df = 3, 78; $R^2 = 0.61$; $P < 0.01$), being shortest when the parent was 3 d old ($P < 0.05$; Tukey's HSD) (Fig. 3B). Adult male survivorship seems to extend beyond that of the

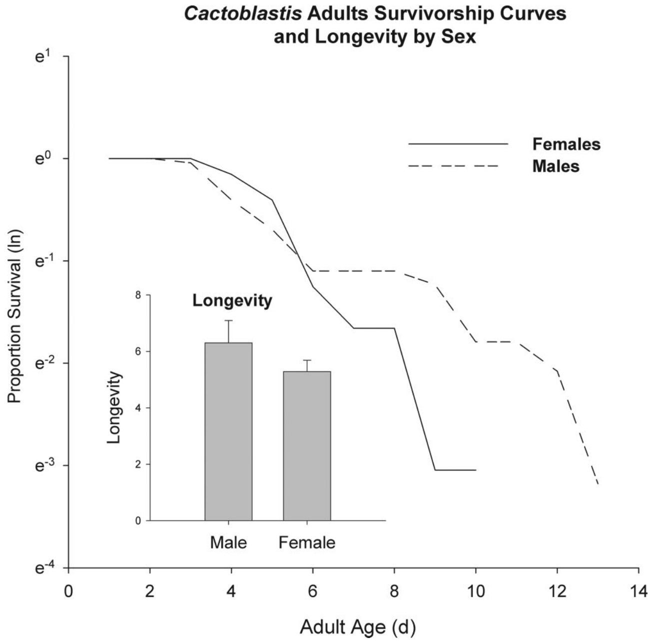

Fig. 4. Survivorship curves and mean adult longevity (inset) by sex. Survivorship is plotted using natural logarithmic scale. There was no difference in adult longevity between the two sexes.

females (Fig. 4). However, there was no significant difference in adult longevity of males (6.3 ± 0.79 d) and females (5.286 ± 0.4) ($t = 1.145$; df = 28.39; $P = 0.262$) (Fig. 4, inset). As in previous studies, female adults (157.8 ± 4.5 mg) weighed more than males (74.9 ± 1.51) ($t = 17.43$; df = 48; $P < 0.01$).

Early descriptions of the biology of *C. cactorum* can be found in Dodd (1940) and Pettey (1948). There are two generations per year in Australia and South Africa: a shorter generation in the summer (October to March) and longer generation in the winter (March to November) (Robertson and Hoffmann 1989). In the warmer climates of the Caribbean and Florida, three generations were recorded (Bloem et al. 2007; Hight and Carpenter 2009; Legaspi et al. 2009). Total lifetime fecundity per female has been found to be 200–300 eggs (Zimmermann et al. 2000). Here, we found a slightly lower estimate with a mean lifetime total of 177.7 ± 14.3 eggs.

A wide variation in the numbers of eggs per egg stick has been reported: 50–100 eggs (Bloem et al. 2007), 60–100 (Zimmermann et al. 2000), or a mean of 54 eggs per stick (range, 4–111; Robertson and Hoffmann 1989). Our results showed a mean of 22.9 ± 3.1 eggs per egg stick, with the highest numbers in 3-d-old females (43.3 ± 3.8). Robertson and Hoffmann (1989) found that each female lays three to four egg sticks, similar to our finding of 4.1 ± 0.38 ($n = 21$; range, 1–6) egg sticks per female lifetime. Percentage of egg hatch declined with female adult age, whereas egg development time increased. Legaspi and Legaspi (2007) reported a similar decline in egg hatch with time. McLean et al. (2006) found that 1-d-old eggs held at a constant temperature of 30°C resulted in the highest percentage of hatch and shortest time to egg hatch. Eggs did not hatch at constant temperatures of 15 or 35°C. Furthermore, the moth's exposure at −10°C for 24 h and at −5°C for 4 d resulted in 100% mortality (McLean et al. 2006). Eggs that were 7- and 14-d-old generally were more resistant to cold temperatures than 1-d-old eggs. As reported by Zimmermann et al. (2004)), adult life span is short, averaging 9 d. Legaspi and Legaspi (2007) found adult longevity of ≈5 d at 34°C, increasing to 12 d at 18°C. Here, adults lived 5–6 d on average, roughly similar to that of females maintained in the 34°C treatment.

This study shows that *C. cactorum* has a narrow window during which oviposition occurs. All oviposition activity occurred between the third and sixth day of adult life. Whether measured in total fecundity, numbers of eggs per egg stick or numbers of ovipositions (egg sticks), most activity occurred on the third day of female adult's life. After the third day, oviposition activity declined with time, although there was a slight increase on the sixth day, which may be attributed to fluctuating environmental conditions in the field. After the third day, not only did oviposition rate decrease but also the quality of eggs produced declined. Percentage of egg hatch decreased and developmental time from egg laying to egg hatching increased. Therefore, from the perspective of mass rearing this moth, the optimal time for collecting eggs is limited to the third day in the life of the adult female.

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