# Development, Longevity, and Fecundity of *Chelonus* sp. nr. *curvimaculatus* (Hymenoptera: Braconidae), an Egg–Larval Parasitoid of Pink Bollworm (Lepidoptera: Gelechiidae)

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Environ. Entomol. 27(2): 443–449 (1998)

**ABSTRACT** Detailed biological information is lacking on *Chelonus* sp. nr. *curvimaculatus*, an egg–larval parasitoid of *Pectinophora gossypiella* (Saunders). We conducted laboratory studies to gain new understanding of the biology of *C.* sp. nr. *curvimaculatus* reared on this economically important host. Developmental time, adult longevity, and fecundity of *C.* sp. nr. *curvimaculatus* were studied under 5 constant temperatures and 3 photoperiods. At 20°C, parasitoid development, from egg to adult, was longer for females (53.6 d) than for males (49.5 d), but at 35°C both sexes developed in a similar period (19.9 d for females and 18.8 d for males). The thermal constant for female and male *C.* sp. nr. *curvimaculatus*, from egg to adult, was 366 and 353 above a base temperature of 12.95°C and 12.47°C, respectively. Adult male (≈16.5 d) and female (≈20 d) parasitoids lived longest at 20°C, and at 35°C both lived ≈6.5 d. True and realized fecundity was highest at 25°C (≈1,034 and 420 eggs per female, respectively) and lowest at 35°C (≈119 and 67, respectively). The percentage of superparasitized host eggs was greatest at 25 and 30°C (≈55%), and lowest at 35°C (≈29%). Net reproductive rates (Ro) were variable across all conditions. Based on the realized fecundity, Ro was highest at 20°C (103.37) and lowest at 35°C (32.79). Temperature and the age of the parasitoid had the greatest influence on fecundity. Photoperiod played a minor role in influencing developmental rates, but not adult longevity or fecundity of *C.* sp. nr. *curvimaculatus*. This life history and rearing information should be useful in field release studies and the development of future biological control programs for pink bollworm.

**KEY WORDS** *Chelonus* sp. nr. *curvimaculatus*, *Pectinophora gossypiella*, biological control, life history

AN IDEAL BIOLOGICAL control agent would be able to regulate a pest species population at a level that is economically acceptable. Ultimately, the success of a predator or parasitoid in a biological control system depends on its ability to reproduce in sufficient numbers to control a pest population. One measure of the potential success of a predator or parasitoid is its fecundity—the number of progeny a female can produce. Extrinsic factors such as temperature, humidity, photoperiod, and nutrition are examples of key environmental elements that may affect fecundity.

*Chelonus* species, egg–larval parasitoids of Lepidoptera, characteristically have high fecundity rates (Broodryk 1969, Rechav 1978b). Thus, these parasitoids are candidates for further research as biological control agents of Lepidoptera.

Field releases of *Chelonus* sp. nr. *curvimaculatus* (red-femur), an egg–larval parasitoid of the pink bollworm, *Pectinophora gossypiella* (Saunders), were made; however, establishment failed (Legner and Medved 1979). The general biology of *C.* sp. nr. *curvimaculatus* is poorly understood, and therefore certain life history traits (e.g., longevity and fecundity as a function of temperature) may have been involved in their failure to establish. The fecundity and longevity of *C.* sp. nr. *curvimaculatus* in relation to pink bollworm were studied; however, the experiments were carried out at one temperature and photoperiod and did not provide information on the parasitoid's reproductive capacity at various field-relevant temperatures and photoperiods (Legner and Thompson 1977). The life cycle and morphology of *C.* sp. nr. *curvimaculatus* has been described (Hentz et al. 1997).

This study investigates the influence of temperature and photoperiod on the development, longevity, and fecundity of *C.* sp. nr. *curvimaculatus*. These investigations will enable us to evaluate the potential of *C.* sp. nr. *curvimaculatus* for future field releases and will also provide vital information for rearing this parasitoid in the laboratory, a critical step in any field release program.

## Materials and Methods

A colony of *Chelonus* sp. nr. *curvimaculatus* (red-femur) was maintained in an insectary at 29 ± 1°C and a photoperiod of 14:10 (L:D) h. *Pectinophora gossypiella*, reared on an artificial wheat germ diet, served as

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0046-225X/98/0443–0449$02.00/0 

the host. General rearing procedures are described in Hentz et al. (1994). The *C.* sp. nr. *curvimaculatus* colony was used to supply individuals for the following studies.

**Parasitoid Development.** A parental group of *C.* sp. nr. *curvimaculatus* was cultured to supply progeny for longevity and fecundity studies. Ovipositional chambers ($n = 45$) were placed in an insectary at 30 ± 1°C and a photoperiod of 14:10 (L:D) h. Each chamber contained 2 or 3 pairs of adult parasitoids 1–4 d old. The chamber was a polystyrene petri plate (150 by 15 mm) containing a moist cotton dental wick on the bottom and a dab of honey on the lid. One egg sheet (≈3.8 by 5.1 cm) containing between 350–450 pink bollworm eggs was placed into each ovipositional chamber for 24 h. Afterward, each egg sheet was removed and individually placed into separate diet containers. Three diet containers each were placed into 1 of 15 conditions (20, 25, 30, 33 or 35 ± 1°C, each with a photoperiod of 10:14, 14:10 or 16:8 (L:D) h).

The 20, 33, and 35°C conditions were maintained by Percival (Boone, IA, USA) environmental chambers, and the 25 and 30°C conditions were maintained in temperature-controlled rooms. Photoperiods were maintained with photoperiod boxes (modified Action Packer Container; Rubbermaid, Wooster, OH) fitted with a fluorescent light fixture (one 8-W bulb; Lampi, F8T5 WW). Photoperiods were controlled with a digital programable plug-in lamp and appliance timer (model DT1, Intermatic, Spring Grove, IL). Temperatures were monitored continuously with a Tattletale Lite (Onset Computer, N. Falmouth, MA) data logger modified to record temperatures for 8 of the 15 controlled environments. Humidity was not controlled or monitored.

Each diet container was monitored daily for the emergence of adult parasitoids. This was used to estimate developmental time, from egg to adult. Developmental times were converted to rates (1/day), and the average rate of development was calculated separately for males and females in each condition. These means ± SD were used to estimate the parameters for the nonlinear model described by Logan et al. (1976):

$$d(t) = \mathrm{psi}[\exp\{\mathrm{rho}(T - Tb)\} - \exp\{\mathrm{rho}(Tm - Tb) - (Tm - T)/\Delta T\}], \quad [1]$$

where psi is the rate of development at *Tb*; rho is the rate of increase at the optimal temperature; *T* is temperature; *Tb* is the base temperature; *Tm* is the maximum temperature at which any development can occur; and $\Delta T$ is the temperature range at which "thermal breakdown" becomes the dominating factor. Deltagraph software (DeltaPoint 1993) was used for parameter estimation of the nonlinear model.

The nonlinear model was used to estimate *T* opt, the temperature at which the rate of development is maximum. A linear model (Campbell et al. 1974) was used to determine thermal constants (degree-days [DD]) and lower developmental thresholds (*TL*) from developmental rates from egg to adult. Based on the calculated Topt (≈33°C), data from 35°C were excluded from the linear model.

We used *t*-tests to determine if the slopes of the linear regression models for the different photoperiods were homogeneous. An analysis of variance (ANOVA) with interactions (SAS Institute 1994) was used to examine differences in developmental times among treatments.

**Longevity and Fecundity.** Each test group consisted of 10 pairs of adult parasitoids that emerged on the same day under the same conditions. In the treatment at 20°C and a photoperiod of 16:8 (L:D) h, only 9 females were used; in the treatment at 35°C and 14:10 (L:D) h, there were no parasitoids available to test; in the treatment at 35°C and 16:8 (L:D) h, only 6 pairs were tested. Each pair of *C.* sp. nr. *curvimaculatus* was placed in an ovipositional chamber (100- by 20-mm petri plate), given food and water as before, and allowed to acclimate for 24 h before host eggs were supplied.

Host egg sheets (≈2.5 by 3.8 cm) containing a known number of eggs (mean = 180; range, 106–446) 1–3 d old were replaced daily until the death of the female. All eggs supplied to the test groups on a given day were of the same age. Unused pink bollworm egg sheets were stored at 20°C until they were needed. Longevity of both male and female parasitoids was recorded for each of the pairs relative to the day of adult eclosion.

After egg sheets were retrieved, they were stored in a freezer until they could be dissected for parasitoid eggs. Pink bollworm eggs were dissected according to methods previously described (Hentz et al. 1997). Desiccated host eggs were rehydrated by placing the entire egg sheet on a moist paper towel for ≈12 h before dissection.

It was not feasible to dissect every host egg, therefore only a subsample from each egg sheet was dissected and the total number of parasitoid eggs was estimated. An initial subsample of 30 eggs from each egg sheet was used to estimate *p* and *q* in the following equation described by Snedecor and Cochran (1980) for determining the required sample size from an infinite population:

$$n = 4pq/L^2, \quad [2]$$

where *n* is sample size; *p* is an estimate of the proportion of pink bollworm eggs parasitized; *q* is equal to 1 - *p*; and *L* is the error limit (±10%). Because the exact number of host eggs per egg sheet was known, a revised sample size ($n'$) was calculated based on a finite population *N* (Snedecor and Cochran 1980):

$$n' = n/(1 + \phi), \quad [3]$$

where $\phi$ is equal to $n/N$. As a result, ≈25% of the host eggs per egg sheet were dissected, which gave a reliable estimate of the whole egg sheet. The number of parasitoid eggs or neonate larvae was recorded for each host egg dissected, and any host egg that contained more than 1 parasitoid egg or larva was denoted as superparasitized.

**Table 1. Mean developmental times in days at constant photoperiods and temperatures for *C. sp. nr. curvimaculatus* from egg to adult emergence**

| Gender | Photoperiod (L:D) h | Mean developmental times (±SD), at temps, °C | | | | |
|---|---|---|---|---|---|---|
| | | 20 | 25 | 30 | 33 | 35 |
| Males | 10:14 | 50.3 (2.6)<br>212[a] | 28.7 (1.2)<br>250 | 19.9 (1.0)<br>304 | 18.3 (0.9)<br>163 | 19.8 (1.0)<br>10 |
| | 14:10 | 47.6 (3.2)<br>140 | 26.9 (1.5)<br>172 | 19.0 (1.0)<br>119 | 18.2 (0.4)<br>59 | 18.8 (0.8)<br>12 |
| | 16:8 | 50.0 (3.8)<br>124 | 27.4 (1.2)<br>227 | 19.5 (1.0)<br>147 | 18.2 (0.6)<br>51 | 18.2 (0.4)<br>16 |
| Combined males | | 49.5 (3.4)<br>476 | 27.8 (1.5)<br>649 | 19.6 (1.1)<br>570 | 18.2 (0.8)<br>273 | 18.8 (0.9)<br>38 |
| Females | 10:14 | 55.1 (2.9)<br>89 | 30.6 (1.0)<br>100 | 21.3 (0.9)<br>75 | 19.0 (0.9)<br>23 | 20.4 (1.1)<br>15 |
| | 14.10 | 52.1 (3.9)<br>42 | 28.9 (1.3)<br>46 | 20.3 (0.8)<br>26 | 19.2 (1.0)<br>47 | 19.0 (0.0)<br>1 |
| | 16:8 | 52.8 (3.0)<br>102 | 30.0 (1.4)<br>78 | 20.8 (0.8)<br>121 | 18.7 (0.7)<br>77 | 18.8 (0.4)<br>6 |
| Combined females | | 53.6 (3.3)<br>233 | 30.1 (1.4)<br>224 | 20.9 (0.9)<br>222 | 18.9 (0.9)<br>147 | 19.9 (1.2)<br>22 |
| Combined males/females | | 50.8 (3.9)<br>709 | 28.4 (1.8)<br>873 | 20.0 (1.2)<br>792 | 18.5 (0.9)<br>420 | 19.2 (1.2)<br>60 |

[a] *n*, sample size

Two measurements of fecundity were used in this study; "true" and "realized." True fecundity was considered as the total number of eggs oviposited by *C.* sp. nr. *curvimaculatus*, and realized fecundity was equal to the total number of host eggs parasitized (which assumes only 1 parasitoid egg can survive, M. H., unpublished data).

The net reproductive rates (Ro) for *C.* sp. nr. *curvimaculatus* were calculated for both measures of fecundity (Southwood 1966). Immature survivorship was considered 100%, because mortality was not measured. Additionally, a standard estimate of the proportion of female progeny for each condition was used (M. H., unpublished data), because the gender of the parasitoid eggs could not be determined.

The influence of temperature and photoperiod on longevity and fecundity were analyzed using a factorial ANOVA. Data from 35°C were excluded, because data were missing for the 14-h photoperiod and mortality was high at the other photoperiods. Linear regression (SAS Institute 1994) was used to examine the relationship between the number of parasitoid eggs laid and the proportion of parasitized host eggs that were superparasitized. The relationship between host egg density and the proportion of superparasitized host eggs was also analyzed by linear regression.

## Results

**Development.** Rates of development for *C.* sp. nr. *curvimaculatus*, from egg to adult, increased with increasing temperatures until 35°C when developmental times were slower (≈1 d longer than at 33°C) (Table 1). The optimal temperature for development was between 30 and 35°C. There was a significant influence of temperature ($F = 253.61$; df = 4, 2,848; $P < 0.001$), photoperiod ($F = 26.59$; df = 2, 2,848; $P < 0.001$), and gender ($F = 106.67$; df = 1, 2,848; $P < 0.001$). There was also a significant temperature by gender interaction, where males took ≈4 d and ≈1 d less than females to develop at 20 and 33°C, respectively ($F = 318.02$; df = 4, 2,848; $P < 0.001$). The increase in the developmental rate with increasing temperatures was greater for females than males.

The optimal developmental temperature (*T*opt) for males ranged from 32.9 to 33.5 and 32.4 to 33.6°C for females (Table 2). Males required 353 DD to complete their overall development, while females developed in 366 DD (Table 3). The slopes of the overall male and female linear regression models were significantly different ($t = 4.41$; $P < 0.05$). The lower developmental threshold (*TL*) was found to be ≈12.5°C for males and ≈13.0°C for females.

Male parasitoids reared in the 16 h photoperiod required 346 DD to develop into adults which was significantly different ($t = 2.15$; $P < 0.05$) than parasitoids reared in the 10 h photoperiod (354 DD) (Table 3). However, this 8 DD difference is <1 d at most of the temperatures tested. Females reared in the 14 h condition required 388 DD to complete development, which was significantly greater than at either 10 h (359 DD) ($t = 4.99$; $P < 0.05$) or 16 h (364 DD) ($t = 4.31$; $P < 0.05$) conditions (Table 3).

**Longevity.** Adult longevity increased as temperature decreased and males tended to live longer than females, with the exception of 20°C (Table 4). A 3-way factorial ANOVA indicated that there was a significant gender ($F = 5.90$; df = 1, 239; $P = 0.01$) and temperature ($F = 37.95$; df = 3, 239; $P < 0.001$) effect. A temperature by gender interaction was borderline significant ($F = 2.67$; df = 3, 239; $P = 0.05$). Neither photoperiod nor any of the other interactions were significant ($P > 0.05$).

**Fecundity.** At 20 and 25°C, about 50% of a female's lifetime compliment of eggs were oviposited by day 4 or 5, whereas at the higher temperatures, 50% of the eggs were laid by day 2. About 10% of the total eggs laid were oviposited by day 1 at 25°C, while at 20, 30, 33, and 35°C about 25, 25, 40, 40%, respectively, were

**Table 2. Nonlinear model parameter estimates describing the relationships between mean developmental rates (1/day) and temperature for male and female *C.* sp. nr. *curvimaculatus* at different photoperiods**

| Gender | Photoperiod (L:D) h | PSI[a] | Rho | *Tb* | *Tm* | *Td* | Topt, °C[b] |
|---|---|---|---|---|---|---|---|
| Males | 10:14 | 0.1939 | 0.1671 | 9.2267 | 38.8625 | 5.9506 | 32.9 |
| | 14:10 | 0.0481 | 0.1569 | 5.6425 | 39.2651 | 6.2717 | 32.9 |
| | 16:8 | 0.2355 | 0.1562 | 7.7946 | 39.8662 | 6.3761 | 33.5 |
| Combined males | | 0.2031 | 0.1632 | 8.7861 | 39.0509 | 6.0960 | 32.9 |
| Females | 10:14 | 0.1859 | 0.1690 | 9.6300 | 38.8970 | 5.8832 | 32.9 |
| | 14:10[c] | 0.1698 | 0.1673 | 10.0525 | 38.3963 | 5.9313 | 32.4 |
| | 16:8 | 0.1838 | 0.1612 | 9.4933 | 39.7815 | 6.1664 | 33.6 |
| Combined females | | 0.1880 | 0.1646 | 9.2892 | 39.2588 | 6.0421 | 33.2 |

[a] Parameter estimates for Psi, Rho, *Tb*, *Tm*, and *Td* as defined by Logan et al. (1976), equation 1; all models, $r^2 = 0.99$, $P \leq 0.001$; *n* are listed in Table 3. Temperatures used were 20, 25, 30, 33, 35°C.
[b] Optimum temperature for development.
[c] Data from 35°C excluded from model.

oviposited. There were no distinct differences between photoperiods.

The mean life time fecundity (true fecundity) per female was highest at 25°C (≈1,034 eggs) and was lowest at 35°C (≈119 eggs) (Fig. 1). Total fecundity was significantly influenced by temperature ($F = 22.33$; df = 3, 109; $P < 0.001$) but not photoperiod ($F = 1.09$; df = 2, 109; $P = 0.12$), or their interaction ($F = 0.87$; df = 6, 109; $P = 0.52$).

The mean total number of pink bollworm eggs parasitized over the lifetime of female *C.* sp. nr. *curvimaculatus* (realized fecundity) was highest at 25°C (≈420 eggs) and lowest at 35°C (≈67 eggs) (Fig. 1). The number of host eggs parasitized was significantly influenced by temperature ($F = 20.15$; df = 3, 115; $P < 0.001$) but not by photoperiod ($F = 0.83$; df = 2, 115; $P = 0.44$), or their interaction ($F = 0.86$; df = 6, 115; $P = 0.53$).

The proportion of eggs that were superparasitized was just about equal to the proportion that were parasitized once, except at 35°C, where far fewer were superparasitized (Fig. 2). There was a significant influence of temperature ($F = 6.41$; df = 3, 118; $P = 0.001$), but not photoperiod ($F = 0.57$; df = 2, 118; $P = 0.57$), or their interaction ($F = 0.89$; df = 6, 118; $P = 0.50$) on the proportion of host eggs superparasitized.

There was a positive relationship between the number of parasitoid eggs laid and the proportion of parasitized host eggs superparasitized ($F = 256.66$; df = 1, 144; $P < 0.001$; $r^2 = 0.64$). There was a lesser and negative effect attributed to density of host eggs presented to the parasitoids for oviposition ($F = 5.65$; df = 1, 143; $P = 0.02$; $r^2 = 0.04$). As density of host eggs increased, the proportion of superparasitized host eggs slightly decreased.

The net reproductive rate (Ro), based on the true and realized fecundity of *C.* sp. nr. *curvimaculatus* was variable across all conditions (Table 5). The Ro based on the realized fecundity was highest at 20°C (103.37) and lowest at 35°C (32.79), while Ro, based on the true fecundity, was highest at 25°C (226.13) and lowest at 35°C (53.48).

## Discussion

*Chelonus* species develop at different rates depending on the host species (Rechav and Orion 1975, Kumar and Ballal 1990). *Chelonus blackburni* (Cameron) reared on pink bollworm had slightly longer development times than *C.* sp. nr. *curvimaculatus* at all temperatures studied (Jackson et al. 1978). Parasitoid or host species' attributes and rearing conditions can

**Table 3. Lower developmental threshold and degree-days for male and female *C.* sp. nr. *curvimaculatus*, from egg to adult emergence**

| Gender | Photoperiod (L:D) h | *TL*, °C[a] | DD[b] | *n* | *b*[c] | *a*[d] | $r^{2e}$ |
|---|---|---|---|---|---|---|---|
| Males | 10:14 | 12.70 | 354.18 | 929 | 0.00282 | −0.0359 | 0.97 |
| | 14:10 | 12.21 | 351.16 | 490 | 0.00285 | −0.0348 | 0.96 |
| | 16:8 | 12.62 | 346.32 | 549 | 0.00289 | −0.0364 | 0.96 |
| Combined females | | 12.47 | 353.43 | 1,967 | 0.00283 | −0.0353 | 0.96 |
| Females | 10:14 | 13.35 | 359.34 | 287 | 0.00278 | −0.0371 | 0.98 |
| | 14:10 | 12.03 | 387.92 | 161 | 0.00258 | −0.0310 | 0.96 |
| | 16:8 | 12.93 | 363.64 | 378 | 0.00275 | −0.0356 | 0.98 |
| Combined females | | 12.95 | 365.95 | 826 | 0.00273 | −0.0353 | 0.98 |
| Combined males/females | | 12.60 | 357.45 | 2,793 | 0.00280 | −0.03523 | 0.96 |

Parameters were estimated from linear regressions of developmental rates (1/day) on temperature for 3 different photoperiods and both genders.
[a] Lower developmental threshold.
[b] Degree-days.
[c] Slope.
[d] Intercept.
[e] $P \leq 0.001$.

**Table 4. Mean adult longevity (d) of *C.*sp.nr. *curvimaculatus* at constant temperatures**

| Temp, °C | Mean Days (SD) *n* | |
|---|---|---|
| | Male | Female |
| 20 | 16.5(6.8) 28 | 19.8(8.8) 29 |
| 25 | 14.2(6.7) 30 | 12.2(3.6) 30 |
| 30 | 11.6(5.3) 29 | 8.8(2.9) 30 |
| 33 | 9.4(4.4) 29 | 6.1(1.3) 30 |
| 35 | 6.9(1.8) 14 | 6.6(1.5) 16 |

affect development rates. For example, different populations of pink bollworms are known to have different developmental rates (Hutchison et al. 1986). Additionally, gender influences developmental rates. For instance, *C.* sp. nr. *curvimaculatus* males develop faster than females (Table 1).

Temperature, but not photoperiod, had a strong influence on the development, longevity, and fecundity of *Chelonus* sp. nr. *curvimaculatus*. *TL* and *Topt* for *C.* sp. nr. *curvimaculatus* (Tables 2, 3) were very similar to that reported for pink bollworm (12.04 and 32.5°C, respectively) (Hutchison et al. 1986). However, *Chelonus* sp. nr *curvimaculatus* had a shorter immature developmental period (Table 1) than pink bollworm (Hutchison et al. 1986) at all the temperatures tested. Quicker development is beneficial for the parasitoids, because it provides time for acclimation and synchronizes parasitoid reproductive and ovipositional behaviors with pink bollworm emergence and oviposition.

An important intrinsic factor for the success of a biological control agent is its ability to reproduce. Although the potential number of eggs laid by a parasitoid is significant, for biological control purposes a more important attribute of a parasitoid that expresses superparasitism is how many hosts it can parasitize in a given host population. Female pink bollworm adults can live ≈17 d (Philipp and Watson 1971) and lay up to 200 eggs in a lifetime (Noble 1969). The highest net reproductive rate for pink bollworm was found to be 77.81 (Philipp and Watson 1971). The true fecundity for *C.* sp. nr. *curvimaculatus* is generally higher than that of pink bollworm (Table 5); however, the net reproductive rate (realized) was comparable to pink bollworm (Philipp and Watson 1971). In natural environments (i.e., cotton fields), where most host eggs are found between the calyx and carpel wall of a cotton boll, *C.* sp. nr. *curvimaculatus* may be expected to spend more time searching for hosts than in the laboratory. Consequently, the number of eggs parasitized by *C.* sp. nr. *curvimaculatus* would decrease from that estimated in the laboratory. Additionally, the food provided to *Chelonus* (honey and water, in the present study) can affect longevity and fecundity (Rechav 1978a). Thus, it is difficult to predict the overall effectiveness of this parasitoid in the field from our studies.

Superparasitism is quite prevalent in *C.* sp. nr. *curvimaculatus*. On average, at least half the host eggs

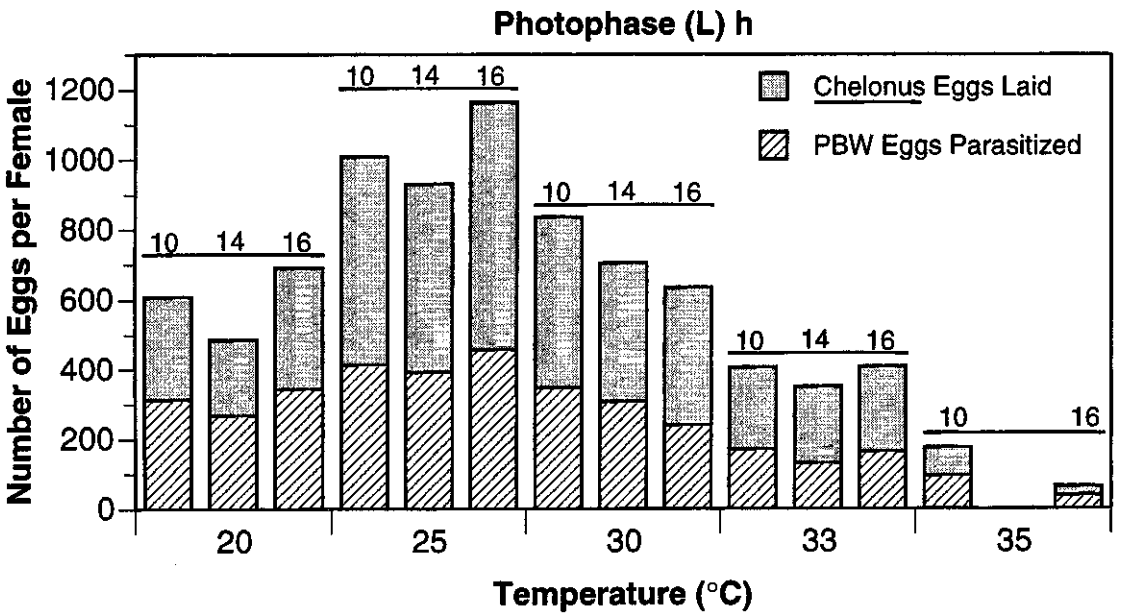


Fig. 1. Mean total number of parasitoid (*Chelonus*) eggs laid and the mean total number of pink bollworm (PBW) eggs that were parasitized over the life time of *C.* sp. nr. *curvimaculatus* under 5 constant temperatures and 3 photoperiods. The photophase indicates hours of light per 24-h period.

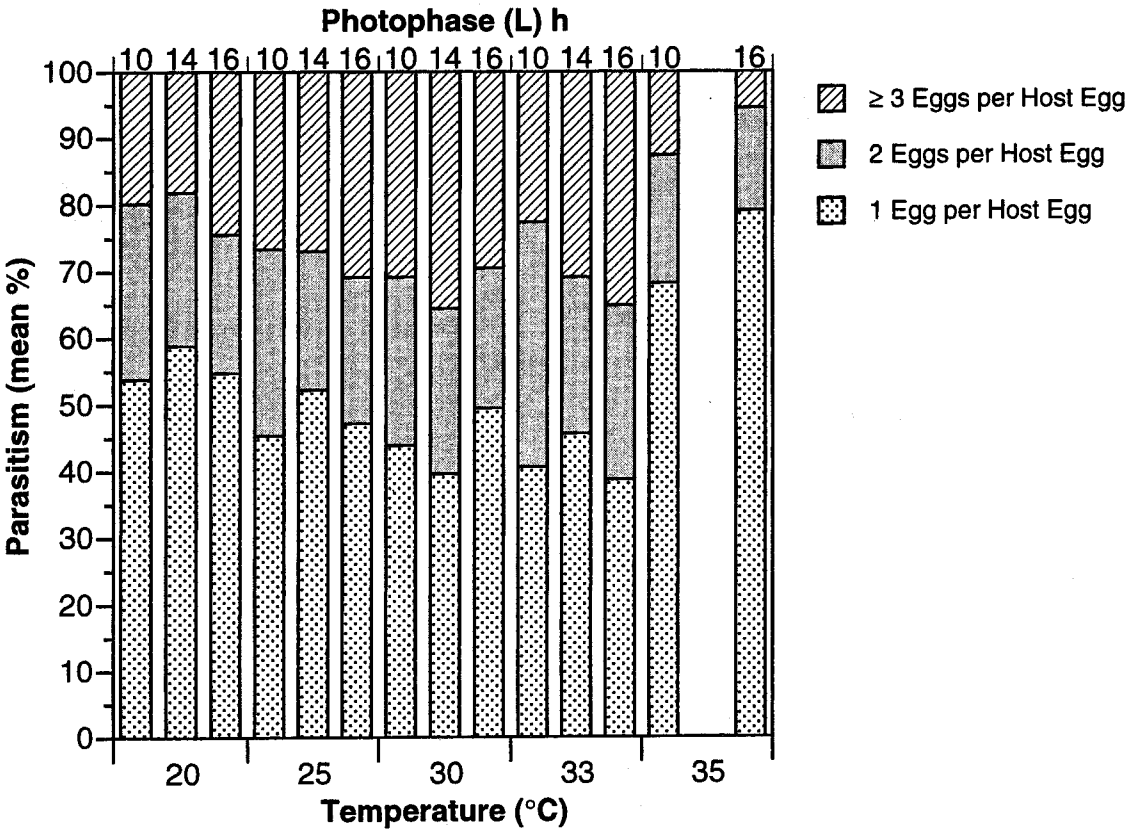


Fig. 2. Mean percent parasitized pink bollworm eggs that contained 1, 2, or ≥ 3 parasitoid eggs at 5 constant temperatures and 3 photoperiods. The photophase indicates hours of light per 24-h period.

presented at one time were superparasitized (Fig. 2). In addition, *C.* sp. nr. *curvimaculatus* tends to show a preference for certain eggs and parasitizes them repeatedly, thus resulting in many instances where a host egg contained multiple parasitoid eggs (>5) from one female. But, only 1 parasitoid completes development in a host (M.H., unpublished data), and superparasitized eggs are less viable than unparasitized eggs (Varma and Mangat 1984). Extensive superparasitism of certain host eggs could not be explained, because *Chelonus* species can apparently distinguish between parasitized and unparasitized host eggs (Ullyett 1949). However, several factors may have influenced this behavior. For example, high mortality can be associated with the early stages of development in *C. blackburni* (Jackson et al. 1979). By over compensating, they might increase the chance that a larva will survive. Egg density, another potential factor, did not appear to be a strong factor in governing *C.* sp. nr. *curvimaculatus*, because rarely did daily parasitism of the host eggs exceed 50%.

Photoperiod did not appear to affect *C.* sp. nr. *curvimaculatus* to an extensive degree. There were some differences in developmental time, which is similar to another Braconid (Hegazi and Führer 1985). Longevity and fecundity were unaffected. We could not de-

**Table 5. Net reproductive rate based on the true and realized fecundity for *C.* sp. nr. *curvimaculatus***

| Measure of fecundity | Photoperiod (L:D) h | Ro[a] at various temps, °C | | | | |
|---|---|---|---|---|---|---|
| | | 20 | 25 | 30 | 33 | 35 |
| True fecundity | 10 | 179.69 | 260.07 | 149.95 | 45.32 | 95.22 |
| | 14 | 112.25 | 177.91 | 126.25 | 140.10 | —[b] |
| | 16 | 312.12 | 240.40 | 259.14 | 245.51 | 11.73 |
| Realized fecundity | 10 | 92.58 | 118.31 | 62.67 | 21.26 | 56.93 |
| | 14 | 61.90 | 74.60 | 55.26 | 58.31 | — |
| | 16 | 155.63 | 94.50 | 108.59 | 99.18 | 8.64 |

[a] Net reproductive rate.
[b] Missing data.

termine if *C.* sp. nr. *curvimaculatus* was simply not influenced by photoperiod or if the artificial light conditions were inadequate (Shields 1989).

While more information is needed to help elucidate reasons for past failures to establish these parasitoids in the field, the present studies add significant information to our understanding of the biology of *C.* sp. nr. *curvimaculatus*. This species performed best in the temperature range of 25–30°C. Although the adult parasitoids did not survive as long as they did at 20°C, they oviposited more eggs and also parasitized more hosts at 25 and 30°C. The average net reproductive rate was similar at 25 and 30°C. The *T*opt and *TL* were similar for both males and females, but DD requirements were generally higher for females. At 35°C, parasitoid larval mortality was high, and adult survival and fecundity were low. Females oviposited fewer eggs and parasitized fewer hosts at 35°C, and Ro was lowest compared with other conditions. Photoperiod did not consistently or conclusively impact life history parameters of this parasitoid.

Future studies should concentrate on the associations between the density of female parasitoids, host eggs, and progeny production for mass rearing of this parasitoid. Superparasitism was extremely high with the current rearing procedures, and so investigations into host location and searching behavior of *C.* sp. nr. *curvimaculatus* could be constructive. Finally, experiments carried out in fluctuating temperatures might provide a more accurate prediction of what would occur in the field. More field release studies should assist in the assessment of this parasitoid as a possible biological control agent.

## Acknowledgments

We thank Joe Ellington (New Mexico State University), Julie Gould (USDA–APHIS, Phoenix) and Glenn Jackson (USDA–ARS, Phoenix) and 2 anonymous reviewers for their critical reviews of earlier drafts of the manuscript. We also thank Jeannette Martin for providing the *C.* sp. nr. *curvimaculatus* colony and all the necessary rearing supplies and Donna Meade for technical assistance.

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*Received for publication 23 January 1997; accepted 30 October 1997.*