Development, Survival, Longevity, and Fecundity of *Clitostethus arcuatus* (Coleoptera: Coccinellidae) on *Siphoninus phillyreae* (Homoptera: Aleyrodidae) in the Laboratory

T. S. BELLOWS, JR., T. D. PAINE, AND D. GERLING[1]

Department of Entomology, University of California, Riverside, California 92521

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ABSTRACT A population of *Clitostethus arcuatus* (Rossi), originating in Israel, was imported into California in 1989. Laboratory studies at three temperatures (21.1, 28.2, 32.2°C) using *Siphoninus phillyreae* (Haliday) as prey indicated maximum developmental rates, survival, and fertility at 28.2°C. At 28.2°C, development from egg to adult required a mean of 15.6 d, egg-to-adult survival was 78%, sex ratio of surviving progeny was 1:1, females lived an average of 82 d and laid an average of 202 eggs. Developmental rates and fertility were slightly lower and survival was similar at 21.1°C. Development was slower and survival and fertility were reduced substantially at 32.2°C.

KEY WORDS Insecta, *Clitostethus arcuatus, Siphoninus phillyreae*, biology

Clitostethus arcuatus (Rossi), a predator of aleyrodids and other insects and mites, is one of several coccinellids reported to feed on whiteflies (Gerling 1990). It is widely distributed in the Mediterranean and surrounding areas, including Lyon (Gautier 1922) and Montpellier (T.S.B., unpublished data), France; the Italian peninsula (Priore 1969, Tremblay 1969, Loi 1978); Sicily (Liotta 1981); Greece (Mentzelos 1967); Israel (D. G., unpublished data); Turkey (Soylu 1980, Ulu 1985); Germany (Bathon & Pietrzik 1986); and in the southern and western portions of the former U.S.S.R. (Ageryan 1977). Ageryan (1977) also reports its distribution to include northern Africa. The species is multivoltine with four generations per year in Italy (Loi 1978, Liotta 1981).

Clitostethus arcuatus is a polyphagous species and has been reported feeding on sympatric aleyrodids native to its Old World distribution (*Siphoninus phillyreae* (Haliday) [Mentzelos 1967, Tremblay 1969], *S. immaculata* (Heeger) [Kirkaldy 1907] and *Aleyrodes proletella* L. [Silvestri 1934, Bathon & Pietrzik 1986]), as well as species introduced to the Mediterranean and Mid-East (*Dialeurodes citri* (Ashmead) [Priore 1969, Ageryan 1977, Loi 1978, Soylu 1980, Liotta 1981, Ulu 1985], *Trialeurodes vaporariorum* (Westwood) [Ageryan 1977], and *Aleurothrixus floccosus* (Maskell) [Liotta 1982]). It feeds on whitefly eggs, nymphs, and adults (Priore 1969, Bathon & Pietrzik 1986), with predation apparently primarily on the eggs and nymphs when all stages are present (Priore 1969). Female adults feeding on eggs of *A. proletella* consumed up to 10,000 eggs per individual (Bathon & Pietrzik 1986). It has been reported feeding on aphids (Ageryan 1977) and on the mite *Tetranychus urticae* Koch (Liotta 1981). It is also cannibalistic; larvae feed on larvae and adults feed on eggs (Liotta 1981; T.S.B., unpublished data). Ageryan (1977) reports *Chrysopa albolineata* L. feeding on larvae of *C. arcuatus*.

In the summer of 1989, *C. arcuatus* was imported from Israel to California as part of a broader program to introduce natural enemies against *S. phillyreae*, which had been introduced previously into California, probably in 1986 or 1987 (Bellows et al. 1990). This paper reports studies on preimaginal developmental times and survival and adult longevity and fecundity of *C. arcuatus* in the laboratory.

Materials and Methods

Clitostethus arcuatus adults and larvae were collected at various coastal sites in Israel and imported into California through the University of California quarantine facility in Riverside, Calif. Colonies were maintained on populations of *Siphoninus phillyreae* infesting ash, *Fraxinus uhdei*, seedlings.

Two series of experiments were conducted at each of three temperatures: 21.1, 28.2, and 32.2°C. In the first series, a number of newly laid (0–24 h old) eggs of *C. arcuatus* were placed individually on ash leaves bearing colonies of *S. phillyreae*. The fate of individual coccinellids was followed daily, and the dates of their molts into successive instars and emergence as adults were recorded, as were the dates of death of any

[1] Department of Zoology, Tel Aviv University, Ramat Aviv, Israel.

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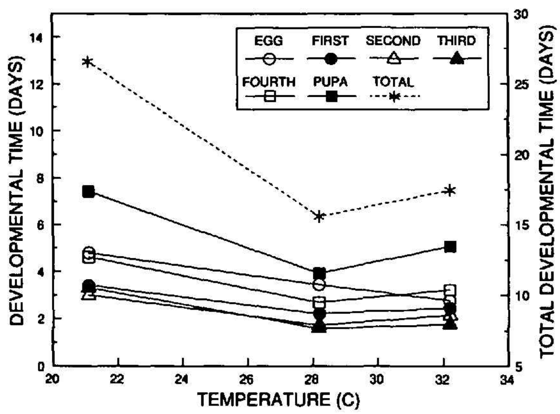

Fig. 1. Developmental time at three temperatures for each preimaginal stage and total developmental time for *C. arcuatus* feeding on *S. phillyreae*.

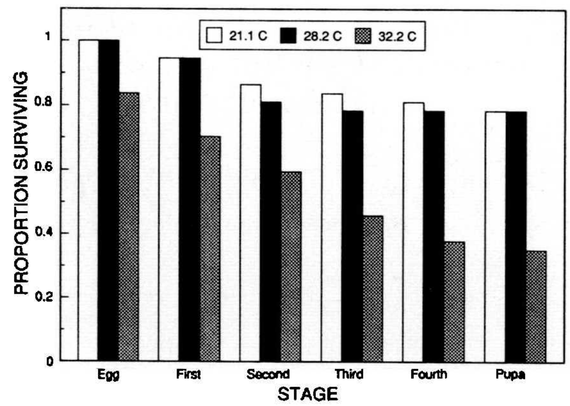

Fig. 2. Proportion of individuals of *C. arcuatus* surviving to the end of each preimaginal developmental stage at three temperatures. Initial number of eggs was 37 at each temperature.

that failed to survive to the adult stage. Each beetle was reared on a single leaf bearing immature stages of mixed ages of the host.

In the second set of experiments, pairs (one male and one female) of newly emerged adults (0–24 h old) were placed on leaves bearing colonies of *S. phillyreae*. Each pair was placed on a new leaf daily, and its survival and oviposition were recorded.

All experiments were conducted in temperature-controlled cabinets (±1°C), a 14:10 (L:D) photoperiod, and ambient relative humidity. In the 32.2°C cabinet, early results indicated that low survival of *C. arcuatus* may have been because of low humidity at that temperature, so humidity was increased by placing large pans of water in the cabinet.

Results

Preimaginal developmental time was shortest for all stages except the egg at 28.2°C (Fig. 1). Development from egg to adult was fastest at this temperature, with a developmental time of 15.59 ± 1.29 ($\bar{x}$ ± SD) (range, 13–18 d; n = 29). One male matured in 13 d and one female matured in 14 d at 28.2°C. The sex ratios of individuals surviving to the adult stage was not significantly different from 1:1 at any temperature.

Preimaginal survival was generally high at the lower two temperatures, with the greatest losses occurring during the second stage (Fig. 2). Overall mortality was greatest at 32.2°C; total survival was less than half that at the other temperatures. Mortality occurred nearly equally in all the younger stages but declined in the fourth instar and pupa.

Mean longevity of adult females varied from 98.9 ± 37.5 d at 21.1°C to 42.1 ± 7.3 d at 32.2°C (Fig. 3). Approximately half the females held at 32.2°C did not oviposit, and these were excluded from the analysis; their mean longevity was slightly less than that of ovipositing females. Mean longevity of adult males was generally 15–20% shorter than female longevity, but these differences were not significant (at the 95% level) for individuals at any temperature. The two longest-lived female adults lived 219 and 158 d at 21.1 and 28.2°C, respectively. The two longest-

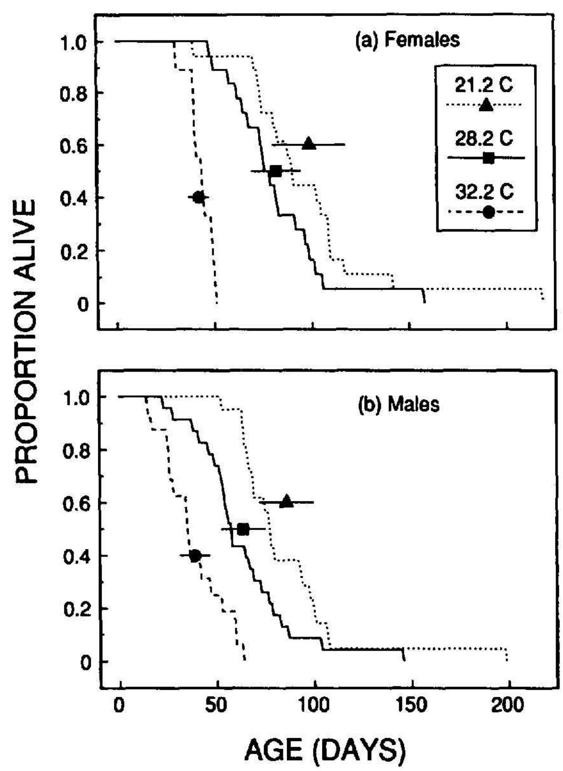

Fig. 3. Longevity of *C. arcuatus* adults. Initial numbers used at 21.1, 28.2, and 32.2°C were, respectively, 18, 18, and 10 in (a) and 21, 23, and 16 in (b). Only females that oviposited were included in (a). Symbols with horizontal bars give life span means ± 95% CIs for the indicated temperatures.

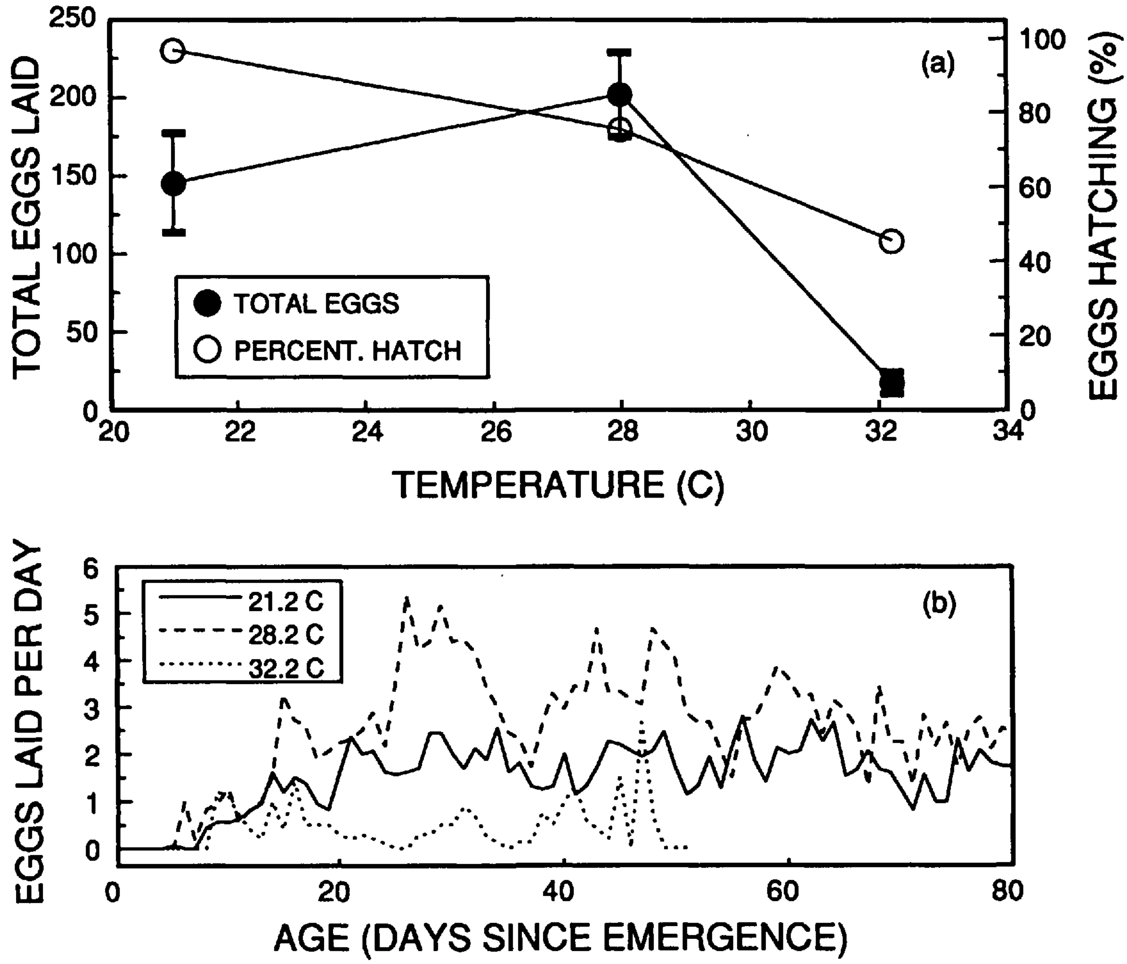

Fig. 4. (a) Total number of eggs laid ($\bar{x} \pm$ SE), and the percentage that hatched, at three temperatures for *C. arcuatus*. (b) Mean number of eggs produced per day by *C. arcuatus* in the first 80 d of female life at three temperatures.

lived male adults lived 199 and 146 d at 21.1 and 28.2°C, respectively.

Fertility of the females varied substantially over the three temperatures, from a mean of 202.0 at 28.2°C to a mean of 17.3 at 32.2°C (Fig. 4a). The total number of eggs laid per individual within a temperature varied also substantially; at 28.2°C, for example, the range was 12–479 eggs per female. The maximum oviposition recorded was 632 eggs from the female that lived 219 d at 21.1°C. The mean fertility, as a fraction of the mean longevity, provides a measure of daily fertility. Values for this daily fertility were 1.47 at 21.1°C, 2.47 at 28.2°C, and 0.41 at 32.2°C. The greater daily fertility of females at 28.2°C was persistent over time (Fig. 4b); the differences in total fertility can be attributed to differences in longevity and to differences in daily fertility at the three temperatures. Eggs in the present study often were laid inside nymphal cases from which whiteflies had emerged; otherwise, they were found on the leaf surface.

The proportion of eggs that hatched in the fertility experiment was less than in the preimaginal survival experiment (Fig. 4a) and ranged from 96.7% at 21.1°C to 45.5% at 32.2°C. The reasons for this difference are not clear. Adult beetles in some of the experiments consumed a few eggs. Any eggs that obviously had been fed upon were excluded from the calculation of percentage hatch. However, the presence of adults may have contributed to an increased reduction in percentage hatching through attempted feeding on the remaining eggs.

The results of preimaginal survival and adult fertility experiments are combined in a life table to provide an overall assessment of the effect of constant temperature on reproduction (Table 1). The greatest rate of reproduction was possible at 28.2°C, with a net reproductive rate of 79.2 progeny per individual per generation. Net reproductive rate was 57.0 at 21.2°C and 3.04 at 32.2°C.

Table 1. Life tables for *C. arcuatus* at three temperatures

	Temperature, °C		
	21.1	28.2	32.2
Preimaginal survival	0.7840	0.7840	0.3510
Fertility	145.44	202.00	17.30
Sex ratio	0.5	0.5	0.5
Net reproduction (R_0)	57.01	79.18	3.036

Discussion

The experimental results obtained in this study indicate that the developmental and reproductive biology of *Clitostethus arcuatus* is strongly affected by constant temperature in the range from 21 to 32°C, with 32°C probably approaching the physiological limit for this population.

Developmental rate was maximal at 28.2°C. Developmental rate was lowest at 21.1°C, probably due to simple poikilothermic reduction in developmental physiology, but it was also lower at 32.2°C than at 28.2°C. The only developmental times reported previously for this species are for field populations. Ageryan (1977) reported egg, larval, and pupal durations of 5, 13–14, and 4–5 d, respectively, at 24–27°C, with a total developmental time of 23–25 d. Loi (1978) reported egg, larval, and pupal developmental times of 3–8, 8–24, and 3–8 d, respectively. Both of these studies were for populations feeding on *D. citri* on citrus, and the results obtained here are in accord with their findings.

Preimaginal survival and adult longevity also were strongly affected by temperature. Optimal results were obtained at 28.2°C. Survival also was high at 21.1°C, but was markedly reduced at 32.2°C. Adult longevity was greatest at the lower temperatures and shortened by as much as 40% at 32.2°C; males were shorter-lived than females at all temperatures. Bathon & Pietrzik (1986) report longevities of up to 150 d at 22–24°C, similar to the maximum longevities obtained in this study at 28.2°C.

Fertility was greatest at 28.2°C, lower at 21.1°C, and reduced to <10% of the maximum value at 32.2°C. The only previous report of fertility is for a field population feeding on *D. citri* on citrus (Loi 1978), where fertility varied from 11 to 41 eggs per female. Average fertility in this study was substantially greater, varying from 17 to 202 eggs per female. Other results (T.S.B., unpublished data) indicate that *D. citri* may not be as suitable a host for *C. arcuatus* as *S. phillyreae*.

The population of *C. arcuatus* imported into California originated in coastal and subcoastal Israel, where the climate is moderated by proximity of the ocean. Similar moderating effects occur along much of the California coast. This initial population of the beetle was released in 1990 in coastal southern California where it became established. The large population growth rates at moderate temperatures found in this study (Table 1) indicate that the species may be able to play an important role in suppression of *S. phillyreae* populations. The ultimate range of this beetle population in California may be limited by climatic tolerances, because much of inland California regularly experiences temperatures in excess of 30°C. Experiments are currently underway to determine the survival and establishment rate of this coccinellid in several California environments. Other populations of the species are known from Old World environments potentially more similar to warmer and more arid parts of California (T.S.B., unpublished data), and these may provide material for additional introductions into California for establishment in areas with warmer climates, should these prove necessary.

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