J. Appl. Entomol. **130(8)**, 437–441 (2006) doi: 10.1111/j.1439-0418.2006.01089.x

Life history of *Axinoscymnus cardilobus* (Col., Coccinellidae), a predator of *Bemisia tabaci* (Hom., Aleyrodidae)

Z. Huang, S.-X. Ren and S.-L. Yao
Department of Entomology, South China Agricultural University, Guangzhou, China

Ms. received: January 21, 2006; accepted: July 10, 2006

Abstract: *Axinoscymnus cardilobus* is an indigenous coccinellid predator in South China, which feeds on many whitefly species. Its development, consumption rate, survivorship, longevity and fecundity on a diet of eggs and nymphs of *Bemisia tabaci* were evaluated. Larval consumption decreased sharply as instars of *B. tabaci* become bigger, and development time of beetle larvae was significantly different when fed on different stages of *B. tabaci*. The sex ratio was 0.44. The performances were better after feeding on whitefly eggs than nymphs. *Axinoscymnus cardilobus* showed good potential for biological control of *B. tabaci*, especially in greenhouse situations.

Key words: *Axinoscymnus cardilobus*, *Bemisia tabaci*, life table, predator

1 Introduction

The sweetpotato whitefly, *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae), is a widespread pest of many tropical and subtropical crops. Although it was first recorded in the 1940s in China (Chou 1949), it has only recently become a severe problem for vegetables and ornamental crops growers in Guangdong (Qiu et al. 2001; Ren et al. 2001) and Beijing (Luo and Zheng 2000; Luo et al. 2000; Zhang 2000), probably through the introduction of a new B biotype with infested poinsettias from the New World (Chen 1997).

There are at least two biotypes (B and non-B) of *B. tabaci* in China (Qiu et al. 2003). *Bemisia tabaci* is attacked by parasitoids and predators (Faria and Wraight 2001; Gerling et al. 2001) with the latter showing great potential in controlling whitefly, such as *Serangium parcesetosum* (Legaspi et al. 1996), *Nephaspis oculatus* (Liu and Stansly 1999; Ren et al. 2002) and *Delphastus cataliae* (Hoelmer et al. 1993; Heinz and Parrella 1994; Liu and Stansly 1999). In China, some 17 predators that have been recorded are oliphagous like *Axinoscymnus cardilobus* Ren & Pang and *Serangium japonicum* Chapin (Yao et al. 2004, 2005) while others are polyphagous like *Chrysopa boninensis* Okanoto, *Chrysopa formosa* Brauer and *Orius sinilis* Zhen (Ren et al. 2001).

Axinoscymnus cardilobus was first found in 1978 in the Dinghu Mountain in Guangdong Province in China (Ren and Pang 1992). Its morphology and certain aspects of life history were described by Huang et al. (2003). However, a detailed study of some important traits is still lacking. The objective of our study was to determine the development, consumption rate, survivorship, longevity, fecundity and demographic parameters of *A. cardilobus* when fed on *B. tabaci*.

2 Materials and Methods

2.1 Insect populations and plants

Both *A. cardilobus* and *B. tabaci* were obtained from ornamental plant [*Codiaeum variegatum* (L.)] in Guangzhou, and were maintained on *C. variegatum* and *Solanum melonena* L. in greenhouse. *Codiaeum variegatum* was grown in 15-cm plastic pots. Sufficient slow-release fertilizer (N : P : K = 13 : 7 : 15, Batian Ecotypic Engineering Co, Ltd, Xili, Shenzhen, China) was added as needed to maintain normal plant growth. *Bemisia tabaci* and *A. cardilobus* were maintained on *C. variegatum* for more than 10 generations before they were used in this study. *Codiaeum variegatum* free of *B. tabaci* were maintained in another greenhouse. Laboratory studies were conducted in an air-conditioned room at 25 ± 2°C, 80 ± 5% RH and a photoperiod of 14 : 10 (L : D).

2.2 Development and consumption of *A. cardilobus* immatures

Adult beetles collected from the stock culture in the greenhouse were fed on *B. tabaci* and maintained on *C. variegatum* plants for egg oviposition. Leaves bearing beetle eggs less than 12 h old were then confined in clear plastic Petri dishes (9 cm diameter) lined with a moist filter paper (8 cm diameter) to prevent desiccation of the eggs. Beetle eggs were divided into two batches and each batch

Table 1. *Average consumption (mean ± SE) of larval instars of* Axinoscymnus cardilobus

	A. cardilobus				
Bemisia tabaci	First instar	Second instar	Third instar	Fourth instar	Total larval consumption
Egg	82.20 ± 6.44	177.46 ± 9.32	311.08 ± 20.22	576.38 ± 25.93	1147.12 ± 36.00
First nymph	39.75 ± 4.31	101.63 ± 18.97	149.88 ± 17.22	469.38 ± 48.92	760.63 ± 53.08
Second nymph	27.88 ± 2.47	51.75 ± 5.77	89.50 ± 5.04	276.38 ± 20.67	445.50 ± 19.83
Third nymph	17.14 ± 1.59	28.29 ± 2.78	56.14 ± 6.09	183.79 ± 11.15	285.36 ± 12.15
Fourth nymph	5.82 ± 0.58	17.27 ± 2.12	33.00 ± 3.41	101.82 ± 9098	157.91 ± 9.05
Pupa	5.00 ± 0.49	10.40 ± 1.28	15.70 ± 1.00	50.50 ± 3.89	81.60 ± 3.89

was divided into three replicates of 50 eggs. The eggs were closely monitored for hatching. The newly hatched neonates were isolated in a plastic Petri dish containing a 10–15 cm^2 leaf disc of *C. variegatum* bearing *B. tabaci*. The neonates in two batches mentioned above maintained on individual leaf disc were then exposed to two different diet treatments namely eggs and assorted immature for consumption. The number of eggs and immatures consumed were recorded daily. The different developmental stages to adult emergence of the beetle and the survival rates of the immatures were also recorded.

2.3 Longevity and fecundity of adults

Twenty-four pairs of newly emerged adults less than 12 h old divided into four groups in two treatments, with two replicates in each treatment were provided with whitefly eggs and immatures on *C. variegatum* leaf in Petri dishes respectively. The daily number of eggs laid, the number of adults surviving each day and the longevity of the adults were recorded. The sex was determined by dissecting dead adults.

2.4 Life table analysis

A cohort of X eggs laid at an interval of 24 h was founded and monitored until appearance of adults. This gave information on age-specific survivorship. Twenty-four pairs of adults were then monitored daily to gain insight into age-specific fecundity. The life table parameters were computed according to Birch (1948):

$$R_0 = \sum L_x M_x$$
$$T = \frac{1}{R_0} \sum x L_x M_x$$
$$r_m = \frac{\ln R_0}{T}$$
$$\lambda = \exp(r_m)$$

where x is the age as days of *A. cardilobus*, L_x is the survivorship at time x, M_x is the number of female eggs (according to the sex ratio) laid per female and per day, T is the mean generation time, R_0 is the net reproductive rate and r_m is the intrinsic rate of increase.

2.5 Data analysis

The length of developmental time, the percentage of survival, the duration of oviposition and the total number of eggs per female were analysed by using analysis of variance (ANOVA), and mean values were separated by using Duncan's multiple range test when the F-value was significant (SAS Institute 1988).

3 Results

3.1 Consumption of beetles in all stages of whitefly

On average, larvae of *A. cardilobus* ate 10–20 times more eggs than pupae of *B. tabaci*. Similarly, the consumption of fourth instar *A. cardilobus* larvae was about 10 times higher than that of first instar larvae (table 1). The per day consumption of adult beetles decreased sharply as whitefly stages increased with values 140.30, 61.00, 34.70, 26.40, 9.80 and 6.70 for egg, first nymph, second nymph, third nymph, fourth nymph and pupa respectively.

3.2 Development of immatures

The incubation period of beetle eggs varied from 3 to 5 days with a mean value of 3.97 days (table 2). Larval development period also varied from 7 to 12 days with duration of the first and fourth instars longer than second and third instars. The development time from egg to adult of *A. cardilobus* varied significantly when fed on different stages of *B. tabaci*; development was faster on a diet of fourth instar nymphs of whiteflies.

3.3 Survival rate of immatures

A diet of eggs or nymphs of *B. tabaci* does not influence survivorship of *A. cardilobus* larvae ($F = 2.82$, d.f. = 1, P = 0.1841 and $F = 3.33$, d.f. = 1, P = 0.1419 for first instars and pupa respectively) (fig. 1). However, second instars proved to be an exception as their survival rate was significantly higher on a diet of eggs ($F = 42.89$, d.f. = 1, P = 0.0028).

3.4 Adult longevity and fecundity

Adult longevity did not vary significantly when fed on whitefly eggs or nymphs ($F = 2.72$, d.f. = 1, P = 0.1130). It varied from 41 to 82 days, with a mean of 68.12 days ($n = 12$) on whitefly eggs and 60.82 days ($n = 12$) on whitefly nymphs (table 3). The pre-ovipositional period was significantly shorter when fed on eggs ($F = 45.00$, d.f. = 1, P < 0.0001). The fecundity of beetle fed on eggs of whitefly was significantly higher than that on nymphs, with mean values of 132.33 and 58.50 for egg and nymphs respectively ($F = 10.73$, d.f. = 1, P = 0.0083). The longest lived female laid 197 eggs over a period of 82 days. The trends of adult beetle oviposition and

Table 2. *Developmental times of different stages of* Axinoscymnus cardilobus *preyed on different stages of* Bemisia tabaci *(days)*

B. tabaci	*A. cardilobus*							
	Egg	First instar	Second instar	Third instar	Fourth instar	Larva	Pupa	Egg-adult*
Egg	3.97 ± 0.05	1.87 ± 0.07 c	1.83 ± 0.07 c	2.12 ± 0.12 b	2.94 ± 0.14 a	8.75 ± 0.24 c	8.48 ± 0.16 b	21.10 ± 0.32 b
First nymph	3.97 ± 0.05	2.63 ± 0.16 a	2.81 ± 0.16 a	2.88 ± 0.13 a	3.19 ± 0.28 a	11.50 ± 0.33 a	8.34 ± 0.23 b	23.81 ± 0.33 a
Second nymph	3.97 ± 0.05	2.75 ± 0.13 a	2.44 ± 0.11 b	2.19 ± 0.13 b	2.94 ± 0.11 a	10.31 ± 0.16 b	7.69 ± 0.13 c	21.97 ± 0.21 bc
Third nymph	3.97 ± 0.05	2.46 ± 0.11 ab	1.64 ± 0.10 cd	1.71 ± 0.07 c	2.21 ± 0.11 b	8.04 ± 0.14 cd	7.25 ± 0.25 d	19.26 ± 0.22 d
Fourth nymph	3.97 ± 0.05	2.18 ± 0.10 bc	1.41 ± 0.10 d	1.55 ± 0.08 c	2.14 ± 0.12 b	7.27 ± 0.19 e	7.10 ± 0.51 d	18.34 ± 0.16 de
Mix nymph	3.97 ± 0.05	2.44 ± 0.09 ab	1.67 ± 0.07 cd	1.83 ± 0.09 bc	2.10 ± 0.08 b	8.04 ± 0.11 cd	7.27 ± 0.17 d	19.28 ± 0.16 d
Pupa	3.97 ± 0.05	2.15 ± 0.08 bc	1.65 ± 0.13 cd	1.60 ± 0.07 c	2.40 ± 0.10 b	7.80 ± 0.20 e	9.45 ± 0.12 a	21.22 ± 0.24 b
F, d.f.		8.79, 6	18.17, 6	10.61, 6	10.11, 6	31.53, 6	26.70, 6	31.09, 6
P		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Values (mean ± SE) in the same column followed by different letters are significantly different (Duncan's multiple range test, $P < 0.05$).
*Egg-adult refers to the developmental time of *A. cardilobus* from egg to adult emergence.

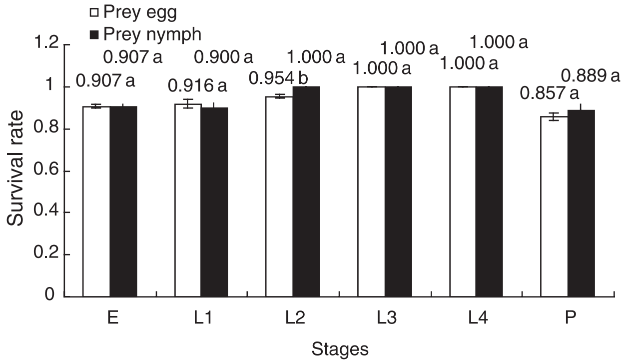

Fig. 1. *Survival rate of* Axinoscymnus cardilobus *in all developmental stages. E, L1, L2, L3, L4 and P denote egg, first nymph, second nymph, third nymph, fourth nymph and pupa stage of beetle respectively. Columns marked by the same letter are not significantly different (Duncan's multiple range test, $P < 0.05$)*

survival ratio per day were different when fed eggs or nymphs of whitefly (figs 2 and 3). The survival rate on a diet of eggs decreased gradually from the 46th day after adult emergence; however, when fed nymphs it decreased from the 33rd day. The line describing egg production throughout time exhibited a more pronounced triangular pattern when *A. cardilobus* larvae were fed on nymphs rather than on eggs of *B. tabaci*.

3.5 Life table

The intrinsic rate of increase and finite rate of increase of the beetles were quite similar on the two types of prey. However, the net reproduction rate on whitefly eggs was more than twice that on whitefly nymphs. The mean generation time on whitefly eggs was also longer than that on whitefly nymphs (table 3).

4 Discussion

Axinoscymnus cardilobus is typically found feeding near the top of plants among the highest densities of whitefly eggs. When fed on *B. tabaci* eggs the beetles were considerably more fecund.

The present study reveals that *A. cardilobus* shares many characteristics, a preference for whitefly eggs over nymphs, and aggregation of pupae on lower leaf surface of certain older leaves, with *N. oculatus* and *Delphastus pusillus* (Hoelmer et al. 1993; Liu and Stansly 1999). However, it consumed more whitefly eggs during larval development than did *N. oculatus* and *D. pusillus*, and daily egg consumption was also higher. The developmental time of *A. cardilobus* was intermediate between that of *N. oculatus* and *D. pusillus* (Hoelmer et al. 1993; Liu et al. 1997). Life history parameters of *A. cardilobus* were obtained under favourable experimental conditions, including high density of prey (whitefly eggs and nymphs), suitable temperature and relative humidity and small arenas. Nevertheless, the intrinsic rate of increase of *A. cardilobus* appears rather lower than that of *N. oculatus* (Liu et al. 1997).

Table 3. *Related statistic and life table parameters for* Axinoscymnus cardilobus *fed on eggs or nymphs of* Bemisia tabaci

Parameters	Prey on eggs	Prey on nymphs
Adult longevity (days)	68.12 ± 0.73 (41–82) a	60.82 ± 0.94 (45–67) a
Preovipositional period (days)	7.31 ± 0.21 (7–8) b	9.33 ± 0.21 (9–10) a
Gross reproductive rate ($\sum m_x$)	132.33 ± 21.45 (73–197) a	58.50 ± 6.91 (40–84) b
Female : male ratio	0.78 : 1	0.74 : 1
Net reproductive rate (R_0)	38.1672	16.1705
Intrinsic rate of increase (r_m)	0.0670	0.0633
Mean generation time (T)	54.7428	44.4435
Finite rate of increase (λ)	1.0685	1.0657

Values (mean ± SE) in the same column followed by different letters are significantly different (Duncan's multiple range test, $P < 0.05$).

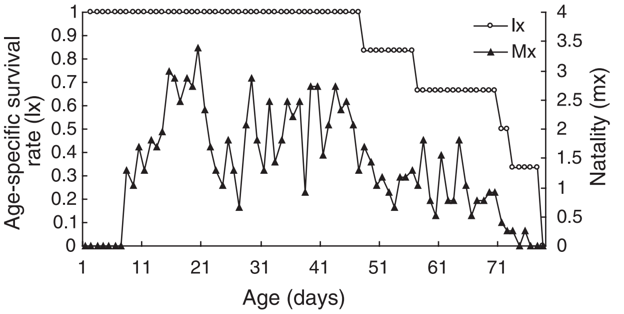

Fig. 2. *The trends of adult beetle age-specific survival rate (l_x) and natality (m_x) on whitefly eggs per day*

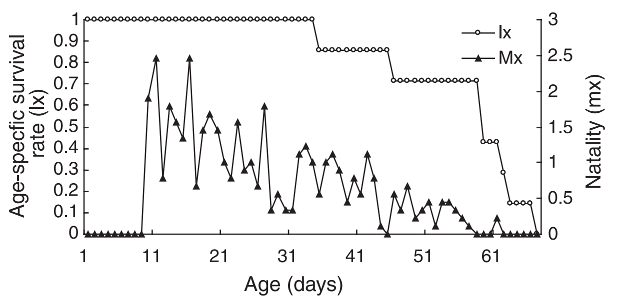

Fig. 3. *The trends of adult beetle age-specific survival rate (l_x) and natality (m_x) on whitefly nymphs per day*

As some results suggest that whiteflies are controlled by a combination of fungal pathogens, predators and parasitoids (Heinz and Parrella 1994; Poprawski et al. 1998; Gerling et al. 2001), are observations tend to indicate that *A. cardilobus* might be a candidate for an integrated control of *B. tabaci*. However, detailed studies on the compatibility of this ladybird beetle with other biocontrol agents are still needed.

Acknowledgements

The authors thank Dr Nasser S. Mandour (College of Agriculture, Suez Canal University, Ismalia, Egypt) and Dr Musa Peter D. (Fourah Bay College University of Sierra Leone, Sierra Leone) for critically going through the early draft. The authors also thank the anonymous reviewers for their invaluable comments and suggestions. The research was funded by grants from the National Tenth Five Research Plan (2001BA509B0604), the National Natural Science Foundation of China (30270901) and the Natural Science Foundation of Guangdong Province (010312).

References

Birch LC, 1948. The intrinsic rate of natural increase in an insect population. J. Anim. Ecol. **17,** 15–26.

Chen LG, 1997. The damage and morphological variations of *Bemisia tabaci* (Gennadius) on ornamental plants. J. Shanghai Agric. Coll. **15,** 186–189 (in Chinese).

Chou Y, 1949. Listo de la konataj Aleurodoj "Homopteroj" en cinio. Entomol. Sin. **3,** 1–18 (in Spanish).

Faria M, Wraight SP, 2001. Biological control of *Bemisia tabaci* with fungi. Crop Prot. **20,** 767–778.

Gerling D, Oscar A, Judit A, 2001. Biological concrol of *Bemisia tabaci* using predators and parasitoids. Crop Prot. **20,** 779–799.

Heinz KM, Parrella MP, 1994. Biological control of *Bemisia argentifolii* (Homoptera: Aleyrodidae) infesting *Euphorbia pulcherrima*: evaluations of releases of *Encarsia luteola* (Hympenoptera: Aphelinidae) and *Delphastus pusillus* (Coleoptera: Coccinellidae). Environ. Entomol. **23,** 1346–1353.

Hoelmer KA, Osborne LS, Yokomi PK, 1993. Reproduction and feeding behavior of *Delphastus pusillus* (Colelptera: Coccinellidae), predators of *Bemisia argentifolii* (Homoptera: Aleyrodidae). J. Econ. Entomol. **86,** 322–329.

Huang Zh, Ren SX, Yao SL, 2003. Morphological and life habit of *Axinoscymnus cardilobus*. Entomol. Knowl. **5,** 450–452 (in Chinese).

Legaspi JC, Legaspi BC Jr, Meagher RL Jr, Ciomperlik MA, 1996. Evaluation of *Serangium parcesetosum* (Coleoptera: Coccinellidae) as a biological control agent of the silverleaf whitefly (Homoptera: Aleyrodidae). Environ. Entomol. **25,** 1421–1427.

Liu TX, Stansly PA, 1999. Searching and feeding behavior of *Nephaspis oculatus* and *Delphastus catalinae* (Coleoptera: Coccinellidae), predators of *Bemisia argentifolii* (Homoptera: Aleyrodidae). Environ. Entomol. **28,** 901–906.

Liu TX, Stansly PA, Hoelmer KA, Osborne L, 1997. Life history of *Nephaspis oculatus* (Coleoptera: Coccinellidae), predator of *Bemisia argentifolii* (Homoptera: Aleyrodidae). Ann. Entomol. Soc. Am. **90,** 776–782.

Luo C, Zheng ZL, 2000. Study progress on *Bemisia tabaci* (Gennadius). Beijing Agric. Sci. **18** (Suppl.)**,** 4–13 (in Chinese).

Luo CJ, Zheng JM, Shi BC, Zhang ZL, 2000. Preliminary investigation of host-plant *Bemisia tabaci* (Gennadius) in Beijing. Beijing Agric. Sci. **18** (Suppl.)**,** 42–47 (in Chinese).

Poprawski TJ, Legaspi JC, Parker PE, 1998. Influence of entomopathogenic fungi on *Serangium parcestosum* (Coleoptera: Coccinellidae), an important predator of whiteflies (Homoptera: Aleyrodidae). Biol. Control **27,** 785–795.

Qiu BL, Ren SX, Sun TX, Sun TX, 2001. Host plant of *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodiae) in

Guangzhou Area. J. South China Agric. Univ. **22,** 43–47 (in Chinese).

Qiu BL, Ren SX, Wen SY, 2003. Biotype identification of populations of *Bemisia tabaci* in China using RAPA-PCR. Acta Entomol. Sin. **46,** 605–608.

Ren SX, Pang XF, 1992. The *Axinoscymnus cardilobus* (Coleoptera: Coccinellidae) from China. Coccinella **4,** 20–23.

Ren SX, Wang ZZ, Qiu BL, Xiao Y, 2001. The pest status of *Bemisia tabaci* in China and non-chemical control strategies. Entomol. Sin. **18,** 279–288.

Ren SX, Stanaly PA, Liu TX, 2002. Life history of the whitefly predator *Nephaspis oculatus* (Coleoptera: Coccinellidae) at six constant temperatures. Biol. Control **23,** 262–268.

SAS Institute, 1988. SAS User's Guide: Statistics. SAS Institute, Cary, NC.

Yao SL, Ren SX, Huang Zh, 2004. The morphological characters and biology of *Serangum japonicum*. Nat. Enemies Insects **26,** 22–27 (in Chinese).

Yao SL, Ren SX, Huang Z, 2005. Feeding behavior of *Serangium japonicum* (Coleoptera: Coccinellidae), a predator of *Bemisia tabaci* (Homoptera: Aleyrodidae). Chin. J. Appl. Ecol. **16,** 509–513 (in Chinese).

Zhang ZL, 2000. Some thoughts to the outbreaks of tobacco whitefly. Beijing Agric. Sci. **18** (Suppl.)**,** 1–3 (in Chinese).

Author's address: Shun-Xiang Ren (corresponding author), Department of Entomology, South China Agricultural University, Guangzhou 510642, China. E-mail: rensxcn@yahoo.com.cn

