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Effects of temperature on development, survival, longevity, and fecundity of the *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae) predator, *Axinoscymnus cardilobus* (Coleoptera: Coccinellidae)

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Abstract

Axinoscymnus cardilobus (Homoptera: Aleyrodidae) is an important predator of *Bemisia tabaci* (Coleoptera: Coccinellidae) that occurs in high population density of *B. tabaci*. Temperature among other factors is observed to play an important role in the development of arthropods. The effect of temperature on the development of *A. cardilobus* was studied at seven constant temperature regimes (14, 17, 20, 23, 26, 29, 32 °C). The results indicated that the duration of egg, larval and pupal stages were significantly influenced by increased temperature. The rate of development gradually increased with increase in temperature from 14 °C to 26 °C, but declined from 26 °C to 32 °C. The survival rates of different insect stages were stable at temperatures between 20 °C and 26 °C, but at extreme temperatures of 32 °C and 14 °C, a sharp decrease was evident. Ovipositional period of the female decreased when temperatures were increased from 17 °C to 32 °C. The highest fecundity of the female (225.7 eggs per female) was recorded at 23 °C. Life tables of *A. cardilobus* were constructed based on the experimental results at temperatures of 14–32 °C. The reproductive rate (R_0), the innate capacity for increase (r_m) and the finite rate of increase (λ) reached the maximum values at 23 °C, of 70.7, 0.059 and 1.062, respectively. The mean generation time (T) decreased with increased temperature from 17 °C to 32 °C, the highest and least values recorded at 17 °C and 32 °C were 112.7 and 38.7, respectively. These results offer valuable insight on the importation and establishment of *A. cardilobus* into new environments with diverse temperature regimes.

Keywords: *Axinoscymnus cardilobus*; Temperature; Development; Survival; Longevity; Fecundity; Whitefly

1. Introduction

The tobacco whitefly, *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae), is one of the most important agricultural pests of many tropical and subtropical crops. Surveys have indicated more than 500 known host plants from 74 families (Mound and Halsey, 1978; Byrne et al., 1990; Cock, 1993; De Barro et al., 1998). Damage is mostly caused by insect feeding on phloem sap of the host crop, thereby inducing physiological disorders such as stunted growth, irregular ripening of fruits, wilting, secretion of excess sugar in the form of honeydew that damages crop quality, and in the case of severe infestation, death of the entire plant (Brown, 1994; Brown and Bird, 1992) *B. tabaci* is also observed to vector important viral diseases of many agricultural crops.

Bemisia tabaci is a serious pest in China and is widely distributed in 13 provinces including Hubei, Xinjiang, Sichuan, Shandong, Shanxi (Ren et al., 2001; Xu, 1996) and exhibits a tendency for annual outbreaks (Zhang, 2000).

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Although *B. tabaci* was first recorded as early as the 1940s in China, its pest status was recently noted (Luo et al., 2000a; Luo and Zhang, 2000b; Ren et al., 2001). There are about 74 species of host plants of *B. tabaci* in Beijing (Luo et al., 2000a; Luo and Zhang, 2000b). The increased pest problem caused by *B. tabaci* is likely due to the introduction of a new B biotype with infested plants through international trade around the world (De Barro et al., 1998; Chen, 1997).

Bemisia tabaci is attacked by parasitoids, predators and fungi (Gerling, 1986,1992,1997; Polaszek, 1992; Lacey et al., 1996; Nordlund and Legaspi, 1996; Heinz et al., 1999; Gerling et al., 2001; Faria and Wraight, 2001). Many predators such as *Serangium parcesetosum* Sicard (Coleoptera: Coccinellidae) (Legaspi et al., 1996), *Nephaspis oculatus* Blatchley (Coleoptera: Coccinellidae) (Liu and Stansly, 1999; Ren et al., 2002), *Delphastus catalinae* Horn (Coleoptera: Coccinellidae) (Hoelmer et al., 1993; Heinz and Parrella, 1994; Liu and Stansly, 1999) have shown potential to control whitefly. In China, approximately 17 predator species have been recorded, including the oliphagous predators *Axinoscymnus cardilobus* Ren & Pang (Coleoptera: Coccinellidae), *S. japonicum* Chapin (Coleoptera: Coccinellidae) and the polyphagous predators *Chrysopa boninensis* Okamoto (Neuroptera: Chrysopidae), *Chrysopa formosa* Brauer (Neuroptera: Chrysopidae), *Orius sinilis* Zhen (Heteroptera: Anthocoridae) (Ren et al., 2001).

Axinoscymnus cardilobus, an indigenous predator of *B. tabaci* was first found in the Dinghu Mountains in Guangdong Province in China (Ren and Pang, 1992). The morphological characters, life history and predation have been reported (Huang et al., 2003, 2006a,b). Because of its potential to control *B. tabaci* as a biological agent, we endeavored to broaden the studies of *A. cardilobus* to include its development, survivorship, longevity, fecundity and integrate the life table analyses to evaluate its population dynamics at seven constant temperatures in the laboratory. It is hoped that the findings of this study will offer a valuable insights on prospect of using this predator as a potential biological agent covering wider geographical regions.

2. Materials and methods

2.1. *Axinoscymnus cardilobus* and *B. tabaci*

Both *B. tabaci* and *A. cardilobus* were collected from the stock colony kept in the Engineering Research Center of Biological Control, Ministry of Education, College of Natural Resource and Environment, South China Agricultural University on *Codiaeum variegatum* (L.) and *Solanum melongena* L. Plants were grown in 15 cm diameter plastic pots and N:P:K fertilizers in the ratio 13:7:15 were added as needed to maintain normal plant growth. *B. tabaci* and *A. cardilobus* were maintained on *C. variegatum* for several generations before they were used in this study. *C. variegatum* free of *B. tabaci* were maintained in another greenhouse.

2.2. Development and survivorship of *A. cardilobus* immature

Adult beetles from the greenhouse culture were placed on *C. variegatum* bearing whitefly eggs for oviposition. Leaves with beetle eggs <12-h-old were excised from the main plants and placed in 9 cm diameter plastic Petri dishes lined with moistened filter papers (8 cm in diameter) at the bottom of the dish. The Petri dishes were then placed in growth chambers (PXY-300QA, Shaoguan Keli Experimental Instrument Co., Ltd., Shaoguan, Guangdong) at seven temperature regimes namely 14, 17, 20, 23, 26, 29, 32 ± 1 °C, at a relative humidity of $75 \pm 10\%$ and a photoperiod of 14:10 (L:D). This temperature range covers diverse geographical regions that might influence the physio-ecological activities of the predator. Cohorts of at least 60 eggs were selected, for each treatment with three replicates; eggs were monitored daily until all had hatched. The neonates were gently removed from the leaves and transferred using a fine hairbrush (No. 00) to fresh leaf disks of *C. variegatum* leaf of 10–15 cm^2 bearing immature whitefly in a Petri dish. Leaf disks were replaced daily except during the pupal stage. Beetle was monitored daily until adult emergence, molting of the different developmental stages and mortality occurring at each stage.

2.3. Longevity and fecundity of adults

Newly emerged adults were individually placed on a leaf disk infested with whitefly eggs. After mating, a total of 15 pairs were placed separately on a leaf disk of 5–8 cm diameter with a moistened filter paper lined at the bottom of a Petri dish and kept at each temperature in the growth chamber. Fresh leaf disks with whitefly eggs were provided daily as a source of food. The number of eggs laid, the number of adults surviving each day and the longevity of the adults were recorded daily until all beetles died. The sex of each adult was determined after death by dissecting and exposing the reproductive organs.

2.4. Data analysis

Developmental times, survival rates after an arcsine square-root transformation to normalize the data, adult longevity, ovipositional periods and total number of eggs per female at seven constant temperatures were analyzed using one-way analysis of variance (ANOVA), and means separated by Duncan's Multiple Range Test (DMRT) when F value was significant (SAS Institute, 1988). Developmental rates for each life stage and total life cycle at each temperature was determined as the reciprocal of developmental times. Regression analyses of developmental rates versus temperature (SAS Institute, 1988) were conducted for each life stage and total life cycle by pooling the data. The linear regression equation $[V = (1/K) \times T - C/K]$

was used, where V is the developmental rate in days at temperature T (°C), K is the required heat units in degree-days (DD) in effective accumulative; C is the minimum developmental thresholds (DT) (Ding, 1980). The life table parameters were computed according to Birch (1948), described as:

$$R_0 = \sum l_X M_X$$
$$T = \sum_{\chi} L_{\chi} M_{\chi} / R_0$$
$$r_m = \ln r_0 / T$$
$$\lambda = \exp(r_m)$$

where subscript X is the age in days of *A. cardilobus*, L_X is the survivorships at time x; M_X is the mean number of female offspring produced per surviving female adult during the age interval x. T is the mean generation time; R_0 is the net reproductive rate; r_m is the intrinsic rate of increase.

3. Results

3.1. Temperature effects on development and survivorship of A. cardilobus immature

The effects of different temperatures on developmental period for egg, 1st, 2nd, 3rd, 4th larval instars, pupa and egg to adult emergence of *A. cardilobus* were significantly different (Table 1), and more notable at low temperatures from 14 °C to 23 °C. Total developmental period from egg to adult duration were four times longer at 14 °C than at 32 °C (Table 1). Generally, the development period for eggs, 1st, 2nd, 3rd, 4th larval instars, pupa and egg-adult decreased with increased in temperature from 14 °C to 29 °C (Table 1). However, above 29 °C, the development periods for eggs and 3rd instars increased while those of 2nd, 4th instars and pupa decreased, respectively.

In addition temperature was observed to have a significant effect on percentage survivorship for all larval instars' (Table 2) ($P < 0.0001$). The survival rates of different stages of the beetle were almost stable at temperatures between 20 °C and 26 °C. Below 20 °C and above 26 °C the survivorship of the beetle declined significantly. Of the seven developmental stages, survivorship rate of eggs, 1st instars and pupae were lower as compared to that of 2nd, 3rd and 4th instars (Table 2). The mortality of the beetle in the early instars was higher than that in the later instars. Overall survivorship rate from egg to adult varied from 7.0 at 23 °C to 3.3 at 14 °C.

3.2. Degree-day requirement of A. cardilobus

Lower thermal thresholds and degree-day requirements were estimated for the beetle from the linear regression equation developed to describe the relationship between developmental rate and temperature (Table 3). The highest threshold temperature for development was noted for the pupa stage. According to the biological characteristics of the threshold temperature for the development and the effective accumulative temperature of insect, the threshold temperature for *A. cardilobus* to complete development from egg to adult was 9.07 °C, and effective accumulative temperature was 315.3 degree-days.

3.3. The longevity, preovipositional period, ovipositional period, fecundity and sex ratios of A. cardilobus

The effect of temperatures on longevity, preovipositional period, ovipositional period, fecundity and sex ratios of beetle adults was significantly different (Table 4). The longest preovipositional period of the beetle was 19.7 days at 17 °C while the shortest was 7.8 days at 26 °C. Oviposition period of the female beetle was significantly shorter when temperatures were increased from 17 °C to 32 °C. The highest fecundity of the beetle was recorded as 210.6 eggs per female at 23 °C. Average longevity varied from 163.1 days at 17 °C to 49.3 d at 32 °C. The influence of temperature (T) on oviposition (Y) can be described by the following equation:

$$Y = -1.86T_2 + 82.43T - 724.50 \ (r = 0.9932, P < 0.05)$$

Using the above equation, the value of the minimum and maximum temperature of oviposition when $Y = 0$ were calculated as 12.53 °C and 32.33 °C, respectively. The minimum value of sex-ratio was observed at 23 °C, with a significant increase at the highest temperature (32 °C).

Table 1
Means (±SE) developmental time (in days) of different stages of *A. cardilobus* at seven constant temperatures

Temp (°C)	Egg	Larval instars				Pupa	Egg-adult
		1st instar	2nd instar	3rd instar	4th instar		
14	9.9 ± 0.9a (60)	6.7 ± 0.4a (44)	5.7 ± 0.5a (23)	6.7 ± 0.4a (19)	9.3 ± 0.5a (16)	23.9 ± 1.6a (15)	62.3 ± 1.1a (11)
17	9.8 ± 0.6a (60)	4.9 ± 0.7b (50)	3.5 ± 1.1b (28)	3.9 ± 0.2b (21)	4.7 ± 1.2b (18)	16.5 ± 1.5b (18)	42.7 ± 0.7b (15)
20	6.0 ± 0.8b (60)	3.2 ± 0.9c (55)	2.3 ± 0.8c (38)	2.3 ± 0.9c (37)	3.9 ± 1.1c (36)	11.1 ± 1.3c (36)	28.6 ± 1.3c (32)
23	4.1 ± 0.7c (60)	2.0 ± 0.6d (57)	1.6 ± 0.5d (53)	1.6 ± 0.5d (52)	2.5 ± 1.1d (50)	8.1 ± 0.8d (49)	19.8 ± 1.6d (45)
26	3.9 ± 0.5c (60)	1.9 ± 0.9d (54)	1.5 ± 0.7d (50)	1.5 ± 0.9de (50)	2.4 ± 0.8d (50)	7.3 ± 1.2e (50)	18.8 ± 1.4d (44)
29	3.1 ± 0.7d (60)	1.9 ± 0.8d (48)	1.5 ± 0.6d (37)	1.3 ± 0.7e (37)	2.3 ± 1.0de (35)	5.8 ± 1.4f (34)	15.5 ± 1.6e (29)
32	3.2 ± 0.7d (60)	1.9 ± 0.8d (49)	1.4 ± 0.6d (30)	1.4 ± 0.9e (26)	1.9 ± 0.7e (24)	5.5 ± 1.1f (23)	15.5 ± 1.2e (17)
F, *df*	669.52, 6	305.66, 6	197.99, 6	237.46, 6	196.81, 6	643.78, 6	3012.87, 6
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means in the same column followed by the same letters are not significantly different, (DMRT, $P > 0.05$).
Egg-adult refers to the developmental time of *A. cardilobus* from egg to adult emergence.

Table 2
Mean (±SE) percentage survival of the different developmental stages of *A. cardilobus* at seven constant temperatures

Temp (°C)	Egg	Larval instars				Pupa	Egg-adult
		1st instar	2nd instar	3rd instar	4th instar		
14	6.9 ± 0.8c (60)	5.6 ± 1.1c (44)	7.5 ± 0.9c (23)	7.6 ± 0.4c (19)	8.3 ± 0.6b (16)	6.9 ± 0.4c 15()	3.3 ± 1.2d (11)
17	7.5 ± 0.5b (60)	5.8 ± 0.6c (50)	7.0 ± 0.3d (28)	7.7 ± 0.3c (21)	9.5 ± 0.0a (18)	7.5 ± 0.7b (18)	3.8 ± 0.9c (15)
20	8.2 ± 0.4a (60)	6.6 ± 0.9bc (55)	8.8 ± 0.4ab (38)	8.7 ± 0.4ab (37)	9.5 ± 0.0a (36)	8.0 ± 0.4a (36)	5.7 ± 0.8b (32)
23	8.5 ± 0.3a (60)	8.3 ± 0.6a (57)	8.9 ± 0.7ab (53)	8.6 ± 0.5ab (52)	8.8 ± 0.5ab (50)	8.2 ± 0.8a (49)	7.0 ± 0.6a (45)
26	8.0 ± 0.7ab (60)	8.2 ± 0.5a (54)	9.5 ± 0.0a (50)	9.5 ± 0.0a (50)	9.5 ± 0.0a (50)	7.9 ± 0.3ab (50)	6.9 ± 0.6a (44)
29	7.3 ± 0.5bc (60)	7.1 ± 0.7b (48)	9.5 ± 0.0a (37)	8.4 ± 0.4ab (37)	8.7 ± 0.8ab (35)	7.7 ± 0.9b (34)	5.4 ± 0.4b (29)
32	7.4 ± 0.8b (60)	6.1 ± 0.9c (49)	7.8 ± 0.9c (30)	8.2 ± 0.5ab (26)	8.6 ± 0.4ab (24)	6.9 ± 0.9c (23)	4.1 ± 0.9c (17)
F, *df*	15.8, 6	253.6, 6	142.78, 6	311.52, 6	97.87, 6	114.56, 6	24.6, 6
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means in the same column followed by the same letter are not significantly different (DMRT, $P > 0.05$). Data on mean (±SE) percentage survival were subjected to arcsine square root transformation prior to computation.

Table 3
Estimates of the linear regression analyses and lower thermal thresholds and effective accumulative temperature of different stages of *A. cardilobus*

Life stages	Regression equations	R^2	*F* values	$P > F$	*C*	*K*
Egg	$V = 0.0140T-0.1071$	0.94	212.34	0.0001	7.65	64.2
1st instars	$V = 0.0232T-0.1433$	0.84	116.70	0.0001	6.18	5.6
2nd instars	$V = 0.0308T-0.1955$	0.88	98.43	0.0001	6.35	27.2
3rd instars	$V = 0.0345T-0.2813$	0.89	103.41	0.0001	8.15	28.1
4th instars	$V = 0.0222T-0.1749$	0.96	179.67	0.0001	7.88	41.5
Pupa	$V = 0.0083T-0.0753$	0.99	337.20	0.0001	9.07	120.7
Egg-adult	$V = 0.0030T-0.0240$	0.96	204.67	0.0001	9.07	315.3

Calculated after Ding (1980), where *t* is the temperature (°C) and *V* is the developmental rate (1/developmental time).
K, the effective accumulative temperature of insect degree-days.
C, minimum developmental threshold (°C).

Table 4
Mean (±SE) preovipositional period, ovipositional period, fecundity, longevity and sex ratios of *A. cardilobus*

Temp (°C)	Preovipositional period (days)	Ovipositional period (days)	Oviposition (eggs/female)	Longevity (days)	Sex ratio (F/(M + F))
17	19.7 ± 0.6a	109.1 ± 7.5a	124.7 ± 6.7b	163.1 ± 5.0a	0.52 ± 0.08b
20	8.1 ± 0.3c	91.8 ± 13.3ab	197.6 ± 46.4a	98.9 ± 13.1b	0.52 ± 0.07b
23	7.9 ± 0.3c	75.7 ± 14.6b	210.6 ± 32.1a	89.6 ± 11.9b	0.42 ± 0.02c
26	7.8 ± 0.5c	61.4 ± 8.73bc	132.3 ± 31.3b	71.9 ± 8.4c	0.44 ± 0.08c
29	10.9 ± 0.45b	53.4 ± 3.1c	92.9 ± 7.7c	74.6 ± 4.2c	0.48 ± 0.05bc
32	8.8 ± 0.7c	16.9 ± 5.7d	20.2 ± 10.3d	34.1 ± 7.6d	0.56 ± 0.05a
F, *df*	117.28, 5	10.65, 5	11.07, 5	37.64, 5	21.7, 5
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means in the same column followed by the same letter are not significantly different, (DMRT, $P > 0.05$).

Effect of temperature on sex ratios was noted with an equal ratio of female to male at a temperature of 17–20 °C, but as temperature were increased from 23 °C to 32 °C a shift in ratio was observed towards greater female proportion. The data were subjected to chi square analysis to the expected 1:1 ratio showed no significant difference at $P = 0.05$ suggesting that variation in temperature had no significant effect on the sex ratio when compared to the expected 1:1 ratio ($\chi^2 = 1.4770$, $df = 5$, $P < 0.05$).

3.4. Effects of temperature on age specificity survivorship and fecundity of A. cardilobus populations

Trends of age specific survivorship and fecundity of *A. cardilobus* populations were described at different temperatures (Fig. 1). At 29 °C and 32 °C, over 60% of eggs were laid during the early ovipositional periods marked by a single peak, then followed by sharp decrease with age. In contrast there appeared to be several ovipositional peaks at 17–26 °C. About 100% of the beetle populations survived up to 120 days at 17 °C, but subsequently decreased sharply. Survivorship decreased slowly with the time at 20 °C, 23 °C and 32 °C and was still 50% in the middle of the oviposition period. At 26 °C and 29 °C survivor ratio decreased slowly only at the middle period.

3.5. Life table of A. cardilobus at different temperatures

The reproductive rate (R_0), the innate capacity for increase (r_m) and the finite rate of increase (λ) reached max-

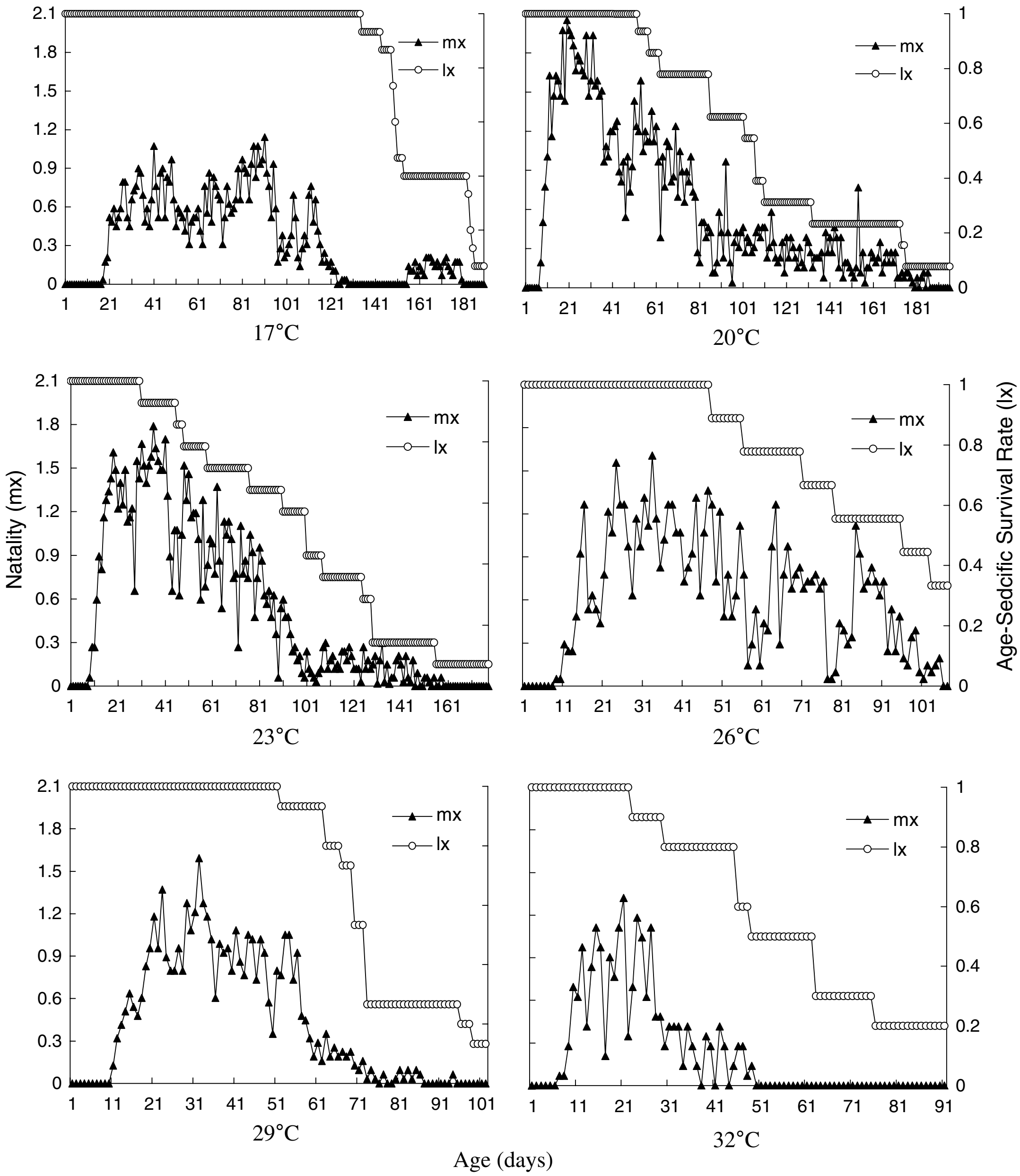

Fig. 1. Age-specific survival rate (l_x) and fecundity (m_x) of *Axinoscymnus cardilobus* at 17, 20, 23, 26, 29, 32 °C.

imum at 23 °C, with values of 70.7, 0.059 and 1.062, respectively, then decreased at higher and lower temperatures(Table 5). The mean length of a generation (T) decreased with increasing temperature. The highest T-value was 112.7 at 17 °C and the lowest T-value was 38.7 at 32 °C. The results indicated that the optimal temperature range for *A. cardilobus* ranged between 20 °C and 26 °C.

4. Discussion

Temperature is important for insect establishment and success (van Lenteren et al., 2006). These studies provide information on temperature that may effect the survival of *A. cardilobus* for importation and release into new environment to control whitefly population in the fields and greenhouses.

Demographic and life table parameters of beetles have been extensively studied by many authors. Ren et al. (2002) estimated the r_m of the lady beetle *N. oculatus* reared on *B. tabaci* eggs at 26 °C as 0.055, whereas Tanigoshi and McMurtry (1977) computed the r_m for predaceous beetle *Stethorus picipes* preyed on mites *Oligonychus punicae* as 0.22 at the same temperature. Our investigation predicted an r_m value of 0.058 when the predator preyed on whitefly nymphs at 26 °C as compared to the values mentioned from the above authors. This diversity in intrinsic rate of increase of predators can be attributed to certain factors such as the nature of the predators prey, the host plants

Table 5
Mean (±SE) life table parameters of *A. cardilobus* at different temperatures

Temp (°C)	N	Intrinsic rate of increase (r_m)	Net reproductive rate (R_0)	Generation time (T) (days)	Finite rate of increase (λ)
17	15	0.025 ± 0.004d	16.6 ± 4.5c	112.7 ± 27.5a	1.025 ± 0.013c
20	15	0.047 ± 0.002bc	65.4 ± 12.6a	89.8 ± 25.5b	1.048 ± 0.005b
23	15	0.059 ± 0.008a	70.7 ± 15.9a	72.2 ± 20.0b	1.062 ± 0.008a
26	15	0.058 ± 0.006a	49.1 ± 9.0b	67.0 ± 20.2bc	1.060 ± 0.007a
29	15	0.054 ± 0.007ab	21.5 ± 3.4c	56.9 ± 10.1c	1.055 ± 0.008a
32	15	0.043 ± 0.011c	5.3 ± 3.3d	38.7 ± 7.9d	1.044 ± 0.014b
F, df		68.25, 5	132.45, 5	76.63, 5	41.71, 5
P		<0.0001	<0.0001	<0.0001	<0.0001

Means in the same column followed by the same letter are not significantly different, (DMRT, $P > 0.05$).
N, total number of three replications.

on which the prey were reared, and the biased male and female sex ratio to name but a few.

Results in this investigation revealed that 20–26 °C was the optimal temperature range for population growth of *A. cardilobus* with a relative high r_m, R_0 and percentage survival. Also combination of the data of fecundity and life table parameters strongly showed that the predator is well adapted to subtropical conditions. The importation of this predator to European regions to be used as a biological control agent against whitefly population would be feasible in the greenhouse where temperatures simulate subtropical conditions, and where the crops suffer from subtropical pests. Although our investigation indicated 23 °C as the optimum temperature for population growth of *A. cardilobus*, however, the intrinsic and finite rates of increase did not vary significantly over the range of 20–26 °C suggesting that performance may not be seriously compromised at most greenhouse conditions.

The lower threshold for development and the thermal constant are useful indicators for an insect potential distribution (Campbell et al., 1974). These findings show that a threshold temperature of 9.07 °C and 204.67 accumulated day degrees were required for *A. cardilobolus* to complete one generation. This clearly suggest that *A. cardilobus* could possibly possess ability to remain active at low temperature in greenhouse cropping systems in most temperate regions where the temperature of greenhouse conditions mostly fall between 14 °C and 18 °C in winter. At 14 °C the biological fitness of the predator was significantly minimized in this study, however, the predator was able to survive to adult emergence although the proportion was insignificant. With regards to outdoor cropping systems were winter temperature may fall as low as 9 °C, i.e. below the developmental threshold of *A. cardilobus*, exposure of *A. cardilobus* to such adverse temperature could drastically reduce its performance hence could not be an ideal candidate for outdoor cropping in winter in Europe and other temperate regions. It has been mentioned by Simmons and Legaspi (2004) that when insects are shipped commercially for biological control purposes, exposure to an extreme low or high temperature may exist for only a relatively short period. The impact of exposure of the beetle survival would depend on both its duration and magnitude. Based on the developmental threshold values and the survival of adult with 100% during 120 days at 17 °C, it is quite apparent that trans-continental shipment of *A. cardilobus* for commercial purpose is possible as the predator would possibly withstand such temperatures.

One major attribute of biological control candidate is the ability of the life cycle of the predator to synchronize with that of the prey. Optimum fecundity and other demographic parameters of *A. cardilobus* occurred at temperature of 20–26 °C. Butler et al. (1983) reported that the maximum fecundity of *B. tabaci* occurred at 26.7 °C. These values suggest that predator and prey would seem to share the same optimum temperature which is a desirable attribute for the predator to suppress *B. tabaci* population. This further suggests *A. cardilobus* as an ideal candidate for biological control of *B. tabaci* population in the fields in tropical regions and in greenhouses in temperate regions.

Our research was designed to investigate effects of temperature regimes on the survival of the predator *A. cardilobus*. Such information would be useful for not only for commercial rearing and shipping of this insect but also for determining the climatic conditions affecting its efficacy as biological control tool against *B. tabaci* population. Our findings indicate that *A. cardilobus* exhibit sufficient environmental plasticity to be a useful biological control agent against *B. tabaci* population on greenhouse and field crops under a wide range of temperature conditions. However, further investigation on the preference of the predator on *B. tabaci* and *Trialeurodes vaporariorum* which is also an important pest in greenhouse needs to be ascertained.

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