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Research Article

Reproductive and developmental parameters of *Aenasius bambawalei* (Hymenoptera: Encyrtidae) as affected by temperature

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Abstract: The life table parameters of the parasitoid wasp, *Aenasius bambawalei* Hayat (Hym.: Encyrtidae) were studied at 25, 30, and 35 °C, 65 ± 5% R. H. and 14L: 10D h. Third instar nymphs of *Pseudococcus solenopsis* Tinesly (Hem.: Pseudococcidae) were used as host for the wasp. Adult longevity and preoviposition period of female wasps were assessed and the raw data were analyzed using the age-stage, two-sex life table. According to the results, the total preovipostion period of females was 17 days at 25 °C and decreased to 13.07 days at 35 °C. The highest and lowest longevity was recorded for females at 25 °C (40.12 days) and males at 35 °C (3.71 days), respectively. The intrinsic rates of increase (r) of *A. bambawalei* were 0.1192, 0.1599, 0.2142 d^{-1} at 25, 30 and 35 °C, respectively. The net reproductive rate (R_0) was calculated to be 38.04, 55.30, and 81.22 eggs/individual at 25, 30 and 35 °C, respectively. The mean generation time (T) of *A. bambawalei* ranged from 20.52 days at 35 °C to 30.52 days at 25 °C. Our results suggested that *A. bambawalei* may be a more efficient biological control agent for *P. solenopsis* at 35 °C than at 25 and 30 °C.

Keywords: Biological Control, Chalcidoidea, Life table, Mealybug, Parasitism

Introduction

The invasive mealybug, *Pseudococcus solenopsis*, native to North America, is a polyphagous pest of cotton, vegetable, and ornamentals with widespread distribution in tropical and subtropical parts of the world (Hodgson, 2008; Wang *et al.*, 2010). In Iran, the pest was reported for the first time on *Hibiscus rosa-sinensis* L. (Malvaceae) from South-East of the country in 2009 (Moghaddam and Bagheri, 2010). Then, in further surveys more than 70 families of various plants were found as its hosts in tropical regions (Fallahzadeh *et al.*, 2014; Mossadegh *et al.*, 2015). *Pseudococcus solenopsis* attacks growing parts of plants, feeds on phloem sap, and secrets large quantities of honeydew which causes growth of black sooty mold and severely reduces photosynthesis of host plants (Prabhakar *et al.*, 2013). Biological, cultural, and chemical control have been used to reduce the

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population of mealybugs; however, presence of hydrophobic waxes on their body prohibits the success of chemical control (Franco *et al.*, 2009).

Lack of proper quarantine, a wide range of ornamental and agricultural crops, and the warm and dry climate of Southwestern Iran provide appropriate conditions for the activity of mealybugs, especially *P. solenopsis* (Moghaddam and Bagheri, 2010; Seyfollahi *et al.,* 2017). In Iran, control of mealybugs is carried out with imported coccinellid, *Cryptolaemus montrouzieri* Mulsant. However, the inability of this predator to tolerate the warm-weather conditions in summer in Southwest of the country causes unsuccessful control of *P. solenopsis* in orchards or ornamental plants (Mossadegh *et al.,* 2015). *Phenacoccus solenopsis* has many parasitoids and predators in this region which are able to make a successful biological control of these pests (Zarghami *et al.,* 2014; Forouzan *et al.,* 2016; Mossadegh *et al.,* 2015; Seyfollahi *et al.,* 2017; Nakhai Madih *et al.,* 2017; Joodaki *et al.,* 2018). Among all natural enemies, a great deal of attention has been paid to encyrtid wasps thanks to the high parasitism rate of mealybugs. Mossadegh *et al.* (2015) reported *Aenasius bambawalei* Hayat, *Anagyrus dactylopii* (Howard), *Anagyrus agraensis* Sarawat, *Anagyrus diversicornis* Mercet., *Anagyrus mirzai* Agarwal & Alam, *Anagyrus*nr *kamali* Moursi, *Promuscideaun fasciativentris* Girault as Encyrtid parasitoids on *P. solenopsis* across different parts of Iran. However, since the first damage report of *P. solenopsis* in Southwest of Iran, *A. bambawalei* has had the greatest potential for use in the control of the pest (Mossadegh *et al.,* 2015).

Among several active natural enemies on *P. solenopsis*, *A. bambawalei* has been reported as a potential agent to significantly suppress the pest population in Iran (Mossadegh *et al.,* 2015; Joodaki *et al.,* 2018), India (Kumar *et al*., 2009), China (Feng *et al.,* 2014), and Pakistan (Bodlah *et al.,* 2010). The parasitoid has been reported from different parts of Khuzestan province and Kish Island in Hormozgan Province (Mossadegh *et al.,* 2015). It is a solitary endoparasitoid which parasitizes the third instar nymphs of *P. solenopsis* and kills the host before maturity (Prasad *et al.,* 2011).

Knowledge on the biological characteristics of natural enemies is vital to use potential species in biological control programs. However, there are a few studies on the parasitizing ability of *A. bambawalei* on *P. solenopsis* (Fand *et al.,* 2011; Feng *et al.,* 2014) and no detailed bionomic studies have been conducted so far. On the other hand, temperature is an important factor which influences the biological characteristics of a parasitoid. In general, the greatest parasitism, development, survival, and fecundity of a parasitoid often happens within a specific range of temperature (He *et al.,* 2015). Providing information about thermal requirements of parasitoids in laboratory is a preliminary step toward the mass rearing and possible use of the species as biological control agents in tropical outdoor crops. This information is also important for predicting the population dynamics of the parasitoids in the environment (He *et al.,* 2015). In this study, the effects of different temperatures were studied on development, longevity, and reproduction of *A. bambawalei*.

Materials and Methods

Mealybug culture

A colony of *P. solenopsis* was established by collecting various stages of the pest from infested *Hibiscus rosa-sinensis* shrubs on the campus of the Agricultural Sciences and Natural Resources University of Khuzestan in April 2016. The insects were then released on potato, *Solanum tuberosum* L., sprouts in rearing containers (24 × 10 × 16 cm) tightly covered by a fine mesh. The colony was kept in the Laboratory of Entomology in the climate chambers at three different temperatures of 25, 30, and 35 ± 1 °C, 65 ± 5% R. H. and 14L: 10 D h.

Parasitoid culture

The parasitoid wasp, *A. bambawalei*, was reared in the laboratory on the colony of *P. solenopsis*. Mummified *P. solenopsis* were collected from the infested twigs of *H. rosa-sinensis* on the above-mentioned campus in April 2016. Every 30 mummies were maintained in a container with some droplets of undiluted honey to feed adult parasitoids after emergence separately at 25, 30, and 35 °C, with 65 ± 5% R. H. and 14L: 10D h. Then, the emerged adults were collected by an aspirator and moved into containers with potato sprouts infested by 3rd instar nymphs of *P. solenopsis.* The containers were covered with a fine mesh and female wasps allowed to oviposit on the nymphs.

Life table studies

This study was conducted at three constant temperatures of 25, 30, and 35 ± 1 °C, 65 ± 5%R.H. and 14L: 10D h. To achieve a cohort of eggs of *A. bambawalei*, 20 newly emerged pairs of the parasitoids (< 24 h old) were collected from the colony and released on 100 of 3rd instar nymphs of *P. solenopsis* (Fand *et al.*, 2011; He *et al.,* 2012) established on potato sprouts in a container covered with a fine mesh net for ventilation. Undiluted honey droplets were used as food source for adult parasitoids on the surface of the container's wall.

The parasitoids were removed after 24 hours. Every day, the containers were inspected for mummies and all mealybugs were allowed to develop until the parasitized nymphs became mummified. The parasitized nymphs were separately maintained in new containers and their development were monitored and recorded until the adult parasitoids emerged or died. After the emergence of adults, males and females of parasitoid were paired. A pair was introduced into a container with 30 third instar nymphs of *P. solenopsis* settled on potato sprouts for oviposition. After 24 hours, the parasitoids were transferred to a new container containing 30 third instar nymph of mealybug. This process was continued until the death of female parasitoids. After transfer of parasitoids to the new containers, the nymphs were placed in incubator and monitored daily. The survival and longevity of both sex and fecundity of females were recorded during the experiments. At least 15 pairs of parasitoids were used in these experiments.

Life table analysis

The data for developmental time, survival rate, and longevity of males and females, and those dying before adult stage, as well as female daily fecundity at different temperatures were analyzed according to the age-stage, two-sex life table (Chi, 1988). The computer program TWOSEX-MSChart (Chi, 2018) was used to estimate the life table parameters.

The adult pre-oviposition period (APOP) (The time between adult emergence and the first oviposition) and total pre-oviposition period (TPOP) (The duration from eggs to the first oviposition) were calculated. The age-stage specific survival rate (s_{xj}) (where x is the age and j is the stage), age-specific survivorship (l_x), age-stage specific fecundity (f_{xj}), age-specific fecundity (m_x), and the population parameters including intrinsic rate of increase (r), finite rate of increase (λ), net reproductive rate (R_0), and the mean generation time (T) were also calculated. The life expectancy was also measured according to Chi and Su (2006). Iterative bisection method and Euler-Lotka equation with age indexed from 0 (Goodman, 1982) was employed for calculating the intrinsic rate of increase:

$$\sum_{x=0}^{\omega} = e^{-r(x+1))} l_x m_x = 1 \tag{1}$$

The net reproductive rate (R_0), mean generation time (T), and finite rate of increase (λ) were calculated as follows:

$$R_0 = \sum_{x=0}^{\omega} l_x m_x \quad (2)$$

$$T = \frac{ln\, R_0}{r} \quad (3)$$

$$\lambda = e^r \quad (4)$$

Bootstrap techniques (Efron and Tibshirani, 1994) were utilized to estimate the variances and standard errors of the population parameters. To obtain less variable and more precise results, 10000 bootstrap iterations were performed. A paired bootstrap test was used to compare the differences among treatments using TWOSEX-MSChart (Chi, 2018).

The relationship between the net reproductive rate (R_0) and N_f yields the number of female adults emerging from N (70, 77 and 76 at 25, 30, and 35 °C, respectively). On the other hand, the total number of eggs produced by all females is equal to the net reproductive rate multiplied by the cohort size. Data analysis and population parameters (Chi, 1988) were calculated via the TWOSEX-MSChart computer program (Chi, 2018).

Results

Development and survivorship

The biological characteristics of pre adult stages of *A. bambawalei* (from egg to pupa) in the body of third-instar nymphs of *P. solenopsis* are provided in Table 1. Out of a cohort of 70, 77, and 76 parasitized mealybugs at the beginning of each experiment, 58, 68, and 71 wasps emerged as pupa at 25, 30, and 35 °C, respectively. Developmental time from oviposition to initiation of mummy formation (pupal stage) was significantly affected by temperature in both females and males ($P < 0.05$). Total developmental periods decreased from 15.92 days to 12.05 days in females and from 17.44 days to 11.77 days in males as temperature rose from 25 °C to 35 °C. Except for 25 °C, at the other two temperatures, the males developed faster than females did.

Adult parasitoids mated soon after emergence from the parasitized mealybugs on the day of emergence at all the temperatures. The adult pre-reproductive period (APOP), total pre-reproductive period (TPOP), oviposition period, fecundity, as well as female and male longevities are listed in Table 2. The APOP was not affected by different temperatures; however, TPOP and oviposition period were significantly decreased ($P < 0.05$) with elevation of temperature from 25 to 35 °C. The oviposition period was 33.35 days at 25 °C and decreased to 21.12 days at 35 °C. The mean fecundity per female was significantly affected by temperature which was maximum at 35 °C (154.32 eggs / female) and minimum at 25 °C (102.42 eggs / female). Maximum daily fecundity showed a similar trend with 8, 13, 16 eggs at 25, 30, and 35 °C, respectively (Table 2). The longevity of males and females was significantly different at the three tested temperatures. Female longevities were 40.12, 25.86 and 22.93 days; however, the male longevities were 29.41, 20.90 and 3.71 days, respectively. Longevity of both males and females was longer at 25 °C, and across all temperatures, females lived significantly longer than males did ($p < 0.05$) (Table 2).

Fig. 1 demonstrates the age-stage-specific survival rate (s_{xj}) which represents the probability of survival for a newborn egg to age x and stage j. In addition to survival, this curve also illustrates the stages' difference, stages' overlapping due to the variable developmental rate among the individuals. The probability that a newly laid egg will survive to the adult stage increases with temperature rise. Specifically, the probability that a newly laid egg would survive to the adult stage was 0.37 and 0.46 at 25 °C, 0.38 and 0.51 at 30 °C, and 0.53 and 0.41 at 35 °C for females and males, respectively. Both females and males developing at 35 °C survived longer than those developing at other temperatures (Fig. 1).

Table 1 Development time of *Aenasius bambawalei* on *Pseudococcus solenopsis* at three constant temperatures.

Sex	Developmental stages	25 °C		30 °C		35 °C	
		Development time (day) (Mean ± SE)	n	Development time (day) (Mean ± SE)	n	Development time (day) (Mean ± SE)	n
Female	Oviposition- mummy form.	8.35 ± 0.15^{Ab}	26	7.1 ± 0.14^{Ba}	29	6.25 ± 0.14^{Ca}	40
	Mummy form.-adult emergence	7.78 ± 0.7^{Ab}	26	7.07 ± 0.14^{Ba}	29	5.8 ± 0.15^{Cb}	40
	Total pre-adult period	15.92 ± 0.21^{Ab}	26	14.17 ± 0.22^{Ba}	29	12.05 ± 0.2^{Ca}	40
Male	Oviposition- mummy form	9.12 ± 0.15^{Aa}	32	7.41 ± 0.09^{Ba}	39	6.58 ± 0.12^{Ca}	31
	Mummy form.-adult emergence	8.31 ± 0.1^{Aa}	32	6.51 ± 0.16^{Bb}	39	5.19 ± 0.21^{Ca}	31
	Total pre-adult period	17.44 ± 0.2^{Aa}	32	13.92 ± 0.86^{Ba}	39	11.77 ± 0.21^{Ca}	31

Values followed by the same capital letters in each row are not significantly different using the paired bootstrap test at 5% significant level.

Values followed by the same small letters in each column are not significantly different in each developmental stage between females and males according to the paired bootstrap test at 5% significant level.

n: Number of replications.

Table 2 Adult life stages of *Aenasius bambawalei* reared on *Pseudococcus solenopsis* at three constant temperatures.

Adult stages	25 °C		30 °C		35 °C	
	Mean ± SE	n	Mean ± SE	n	Mean ± SE	n
Female longevity (day)	40.12 ± 0.85^{Aa}	26	25.86 ± 1.2^{Ba}	29	22.93 ± 1.38^{Ca}	40
Male longevity (day)	29.41 ± 2.03^{Ab}	32	20.9 ± 1.16^{Bb}	39	3.71 ± 1.4^{Cb}	31
APOP (day)	1.08 ± 0.11^{A}	26	1.03 ± 0.09^{A}	29	1.02 ± 0.02^{A}	40
TPOP (day)	17 ± 0.19^{A}	26	15.21 ± 0.26^{B}	29	13.07 ± 0.21^{C}	40
Oviposition period (day)	33.35 ± 0.7^{A}	26	23.86 ± 1.06^{B}	29	21.12 ± 1.4^{C}	40
Fecundity (egg/female)	102.42 ± 1.47^{C}	26	119.1 ± 1.73^{B}	29	154.32 ± 8.4^{A}	40
Maximum daily fecundity	8		13		16	

Values followed by the same capital letters in each row are not significantly different using the paired bootstrap test at 5% significant level.

Values followed by the same small letters in each column are not significantly different in each developmental stage between females and males according to the paired bootstrap test at 5% significant level.

n: Number of replications, APOP: Preoviposition period, TPOP: Total preoviposition period.

The age-specific survivorship (l_x), which describes the change in survivorship of the cohort with age, decreased with elevation of temperature from 25 to 35 °C (Fig. 2). The highest rate of longevity was observed at 25 °C (63 days), while the lowest was recorded at 35 °C (52 days). In contrast, the percentage of time females spent on ovipositing (83.13, 92.27, 92.15 from 25 to 35 °C) increased with temperature elevation. The highest peaks for age-stage specific fecundity (the mean number of fertile eggs produced by a female adult) (8.67 eggs), age-specific fecundity (m_x) (the mean number of fertile eggs produced per individual at age x) (8.5 eggs), and age specific maternity ($l_x m_x$) were observed at 35 °C (Fig. 2).

The negative effect of a decline in temperature on the reproductive values of *A. bambawalei* was observed in the age-specific reproductive curve (v_{xj}). This value constitutes the contribution of individuals of age x and stage j to the future population. The maximum reproductive peak of females reared at 35 °C occurred much earlier i.e. on day 15 (v_{15} = 38.62) than those of females reared at 30 °C (day 18) (v_{18} = 34.87) and 25 °C (day 22) (v_{22} = 24.08) (Fig. 3).

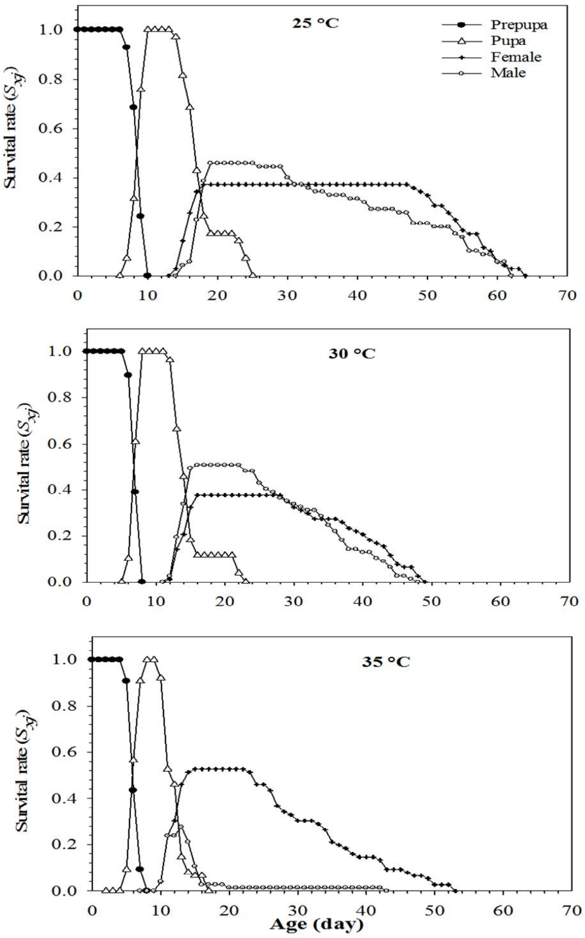

Figure 1 Age-stage specific survival rate (s_{xj}) of *Aenasius bambawalei* on *Pseudococcus solenopsis* at four constant temperatures.

The age-stage specific life expectancy (e_{xj}) of a newborn (e_{01}) *A. bambawalei* is exactly the same as the mean longevity. For both males and females, the maximum life expectancy was obtained at cooler temperature 25 °C which was 63 days and 61 days, for females and males, respectively (Fig. 4). Life expectancy diminished gradually with ageing in this study. The longevity was inversely correlated with temperature and was variable across females and males (Table 2).

Life table parameters

Temperature had a significant effect on all biological parameters of *A. bambawalei* population (Table 3). The values of the intrinsic rate of increase (*r*) increased from 0.1192 d^{-1} at 25 to 0.2143 d^{-1} at 35 °C. The highest value of the finite rate of increase (λ) was observed at 35 °C (1.2389 d^{-1}) while the lowest occurred at 25 °C (1.1266 d^{-1}). The observed trend for net reproductive rates was similar to previous cases with a peak at 35 °C (81.22 eggs/individual). The longest mean generation time (*T*) was recorded at 25 °C (30.52 days) which declined to 20.52 days at temperature of 35 °C.

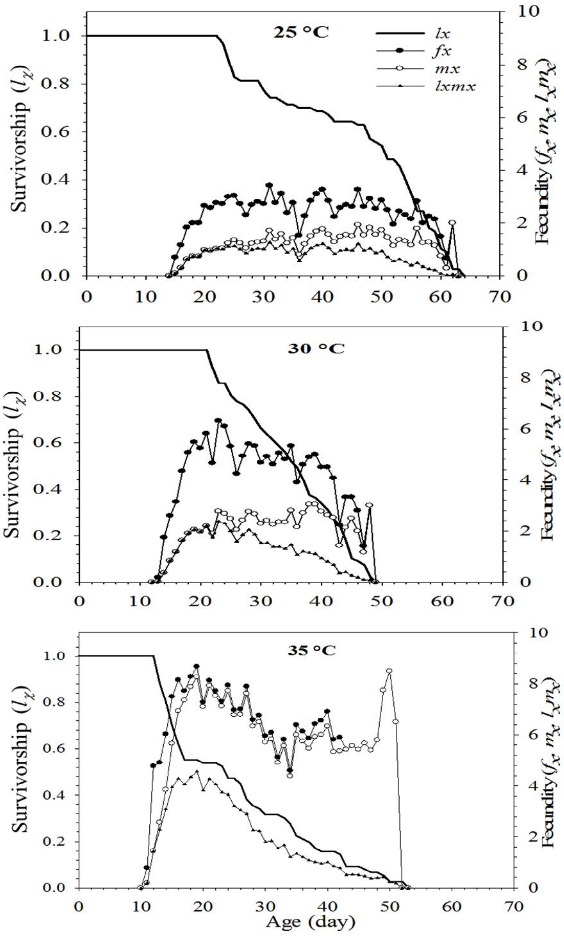

Figure 2 Age-specific survivorship (l_x), age-stage specific fecundity (f_{x3}), age-specific fecundity (m_x) and age-specific maternity (l_xm_x) of *Aenasius bambawalei* on *Pseudococcus solenopsis* at four constant temperatures.

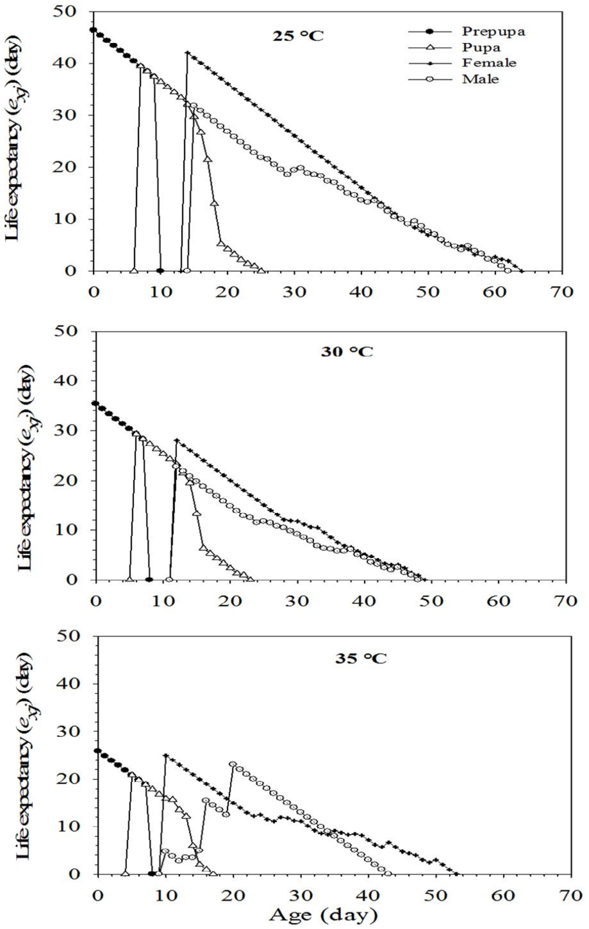

Figure 3 Age-specific reproductive value (v_{xj}) of *Aenasius bambawalei* on *Pseudococcus solenopsis* at four constant temperatures.

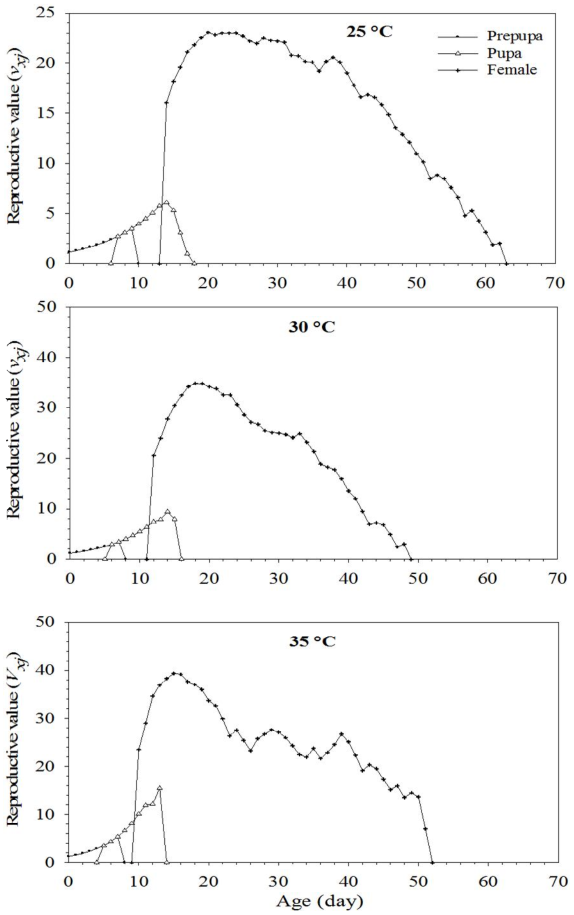

Figure 4 The age-stage life expectancy (e_{xj}) of *Aenasius bambawalei* on *Pseudococcus solenopsis* at four constant temperatures.

Table 3 Mean (± SE) population parameters of *Aenasius bambawalei* parasitizing *Pseudococcus solenopsis* at three constant temperatures.

Temperature (°C)	r (day^{-1})	λ (day^{-1})	R_0 (egg / individual)	T (day)
25	0.1192 ± 0.0063 c	1.1266 ± 0.0071 a	38.04 ± 5.94 c	30.52 ± 0.44 a
30	0.1599 ± 0.0080 b	1.1730 ± 0.0090 b	55.30 ± 9.15 b	25.08 ± 0.52 b
35	0.2143 ± 0.0069 a	1.2389 ± 0.0085 a	81.22 ± 9.87 a	20.52 ± 0.39 c

Values in rows followed by the same small letters are not significantly different using the paired bootstrap test at 5% significant level.

Discussion

In our study, *A. bambawalei* completed its development at 20, 25 and 35 °C. Further, as with other cold-blooded animals, temperature elevation led to a significant reduction in the developmental period of pre-adult stages of males and females. A similar trend was also reported by Pala (2016). In our study, at 25 °C, females' growth, from egg to pupa (8.35 ± 0.15 days), was significantly faster than that of males (9.12 ± 0.15 days). However, at the other two temperatures, there were no significant differences in terms of duration of pre-adult stages. Poorani *et al.* (2009) reported that at 27 °C, the mean duration of developmental time of *A. bambawalei* from egg laying to pupation lasted 8.85 days which was similar to our results at 25 °C, where pupation to adult emergence was 7.35 days in males and 7.00 days in females. Prithvi and Patro (2018) reported that, under laboratory conditions, the mean duration from egg to adult emergence of *Aenasius arizonensis* Hayat was 18.91 days (15-20 days) which was longer than the time at all experimental temperatures in the current study. The difference may be due to various species of parasitoids used in the studies or differences in experimental conditions. Pala (2016) reported significant differences in the pre-adult duration between males and females of *A. arizonensis* at 20 °C (30.56 days for male and 34.40 days for females), and at 25 °C (24.16 days for males and 26.20 days for females). However, no significant differences in pre-adult periods were observed at 30 °C (13.40 days for males and 14.88 days for females) and 35 °C (11.60 days for males and 12.4 days for females). Meanwhile, in Pala (2016) research, males developed faster than females did at all temperatures. Our results are similar to this research, expect for 25 °C, where the female growth was faster than male growth. Savde (2016) reported that at 27 °C the mean developmental periods of males and females of *A. bambawalei* on *P. solenopsis* reared on cotton, okra, potato, and China rose were 12.00 and 13.41; 11.0 and 12.45; 11.62 and 12.27; and 9.57 and 10.08 days, respectively.

Adults of *A. bambawalei* had a short adult preoviposition period (APOP) in the current study and mating occurred very soon after emergence from pupae. Similar results have been previously reported by Pala and Saini (2011), Aga *et al.* (2016), and Savde (2016).

In the current study, oviposition period was shortened significantly as the temperature rose. However, there was no significant difference in oviposition period of *A. bambawalei* at different temperatures as reported by Pala (2016).

The females of the *A. bambawalei* parasitized more hosts at the high temperature of 35 °C (154.32 parasitized hosts/female), while the lowest fecundity (102.42 host/female) occurred at the minimum experimental temperatures (25 °C). Zhang *et al.* (2016) found that the successful parasitism rates of *A. bambawalei* increased at higher temperatures in an experiment with different temperatures of 21, 24, 27, 30, 33, 36, and 39 °C. The highest parasitism rates of *A. bambawalei* on 3rd instar and adult stage of *P. solenopsis* were detected when adult female mealybugs were introduced to *A. bambawalei* at 36 °C, and the lowest value was observed when 3rd instar nymphs were presented at 21 °C. According to pala (2016), the total fecundity of *A. arizonenis* increased from 57.13 eggs/female at 20 °C to 65.60 eggs/female at 30 °C; however, higher temperature of 35 °C had an inverse effect on the fecundity of the parasitoid (37.46 eggs/female). Our review indicated that at different temperatures and host plants, *A. bambawalei* revealed a high reproductive potential similar to our records. For example, the calculated fecundity of *A. bambawalei* on *P. solenopsis* reared on potato sprouts was 100.86 eggs/female at temperatures between 23.2 and 33.2 °C) (Pala and Saini, 2011), 100.5 eggs/female at 27 °C (Aga et al., 2016), 51.66 and 84.67eggs/female on 3rd instar and adult stages of *P. solenopsis* at 28 °C, respectively (Shahzad *et al.*, 2016), 100.17, 100.28, 91.50 and 99.98 eggs/female on *P. solenopsis* reared on cotton, okra, potato, and China rose, respectively (Savde 2016). All fecundities obtained in the above-mentioned researches have been similar to or less than our results at 25 °C.

Further, the fact that the maximum percentage of the time that females spent for oviposition, the highest peaks for age-stage specific fecundity, age-specific fecundity, and achieving the maximum reproductive peak of females far earlier at higher temperatures, suggested the potential of *A. bambawalei* for parasitism at warm weather conditions. Fisher (1930) defined the reproductive value as the contribution of an individual to the future population. The earlier occurrence of the reproductive peak at 35 °C indicates that elevation of temperature from 25 to 35 °C caused an accelerated increase in the population (Fisher 1930). *A. bambawalei* females during mid and late ovipositional periods allocated more energy resources to survival than to reproduction, thus showing reduction in oviposition and increase in survival. He *et al.* (2015) studied reproductive modes and daily fecundity of *A. bambawalei* at 27 °C and reported that the oviposition peak of *A. bambawalei* females occurred on the second day of females' life with 77-day longevity. In our study, the maximum reproduction peak at 35 °C occurred during 15 days of female life (22-day longevity). Probably, the reason for the discrepant results is different experimental conditions (temperature, R. H., and photoperiod).

The longest and shortest adult longevities were recorded at 25 and 35 °C, respectively. Longer life time of female parasitoids compared to males has been reported in previous studies (e.g. Zandi-Sohani *et al.,* 2009; Zandi-Sohani and Shishehbor, 2011). Similar results were observed in other studies like Pala (2016) at 20 °C (female: 38.66 days and male: 23.06), 25 °C (female: 34.53 days and male: 17.26 days), 30 °C (female: 20.86 days and male: 13.20 days) and 35 °C (female: 20.86/male: 10.33). Aga et al. (2016) also reported short longevity of males (16.3 days) when compared to females (26.2 days). Savde (2016) reported the adult longevities of males and females of *A. bambawalei* emerging from *P. solenopsis* as 16.21 and 26.24 days on cotton, 15.74 and 25.84 days on okra, 15.45 and 24.57 days on potato, and 16.08 and 25.45 days on China rose, respectively. Nevertheless, He *et al.* (2015) found that A. *bambawalei* adult females could survive 77 days, which is longer than the results of the present study.

The life table is a useful tool for evaluating the effectiveness of natural enemies for controlling pests under various climatic conditions and in different habitats (Jervis and Copland 1996). Pala (2016) reported an increase in net reproductive rate (R_0) from 29.60 to 36.41 as the temperature increased from 20 °C to 30 °C. However, the net reproductive rate diminished to 20.32 at 35 °C. The generation time (T) declined from 51.96 days at 20 °C to 19.38 days at 35 °C, where the finite rate of increase (λ) was 1.067 at 20 and dropped to 0.155 at 35 °C (Pala, 2016).

Among life table parameters (R_0, r, λ, T), the information of r is especially interesting as it integrates the effects of mortality and fertility in a single value. The maximum intrinsic rate of increase for *A. bambawalei* was recorded as 0.21 d^{-1} at 35 °C, suggesting that this parasitoid had a high potential for population growth at warm temperatures. In Pala (2016) research, the calculated values of r for *A. arizonensis* at 20, 25, 30 and 35 °C were reported as 0.065, 0.083, 0.153 and 0.155, respectively. They also reported that 35 °C is the most favorable temperature for the development and reproduction of the parasitoid. However, in our study, the values for life table parameters were higher. In our research, we used the age-stage, two-sex life table for evaluation of biology and life table parameters of *A. bambawalei* parasitizing *P. solenopsis* as in the context of biological control both sexes must be included. This theory was developed by Chi (1988) which takes stage differentiation, male populations, and variable developmental rates into consideration. However, in Pala's (2016) research, the female age-specific life table was used. Female age-specific life table (Carey, 1993) deals with female populations only and ignores the variable developmental rates of individuals, stage differentiation, and males in a population.

This study provides new information on the effect of temperature on development, survival, adult longevity and fecundity of *A. bambawalei* reared on *P. solenopsis* at constant temperatures in the laboratory; which are essential for understanding its population dynamics on the pest. According to these results, *A. bamabawalei* produced more female progeny at 35 °C as compared to the other temperatures which shows that 35 °C may be used as the best temperature for mass rearing purpose.

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Statement of Conflicting Interests

The Authors state that there is no conflict of interest

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بررسی رشد و تولیدمثل زنبور پارازیتوئید *Aenasius bambawalei* (Hymenoptera: Encyrtidae) در دماهای مختلف

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چکیده: جدول زندگی زنبور پارازیتوئید *Aenasius bambawalei* (Hayat) (Hym.: Encyrtidae) در سه دمای ۲۰، ۲۵ و ۳۵ درجه سلسیوس، رطوبت نسبی ۵ ± ۶۵ درصد و دوره نوری ۱۴ ساعت روشنایی و ۱۰ ساعت تاریکی مورد بررسی قرار گرفت. پوره‌های سن سوم شپشک آردآلود پنبه *Pseudococcus solenopsis* Tinesly (Hem.: Pseudococcidae) به‌عنوان میزبان زنبور استفاده شد. داده‌های دوره پیش از بلوغ و طول عمر زنبورهای ماده با استفاده از جدول زندگی دوجنسی مورد تجزیه تحلیل قرار گرفت. براساس نتایج، طول دوره پیش از بلوغ ماده‌ها از ۱۷ روز در دمای ۲۵ °C به ۱۳/۷ روز در دمای ۳۵ °C کاهش یافت. بیش‌ترین و کم‌ترین طول عمر ماده‌ها به‌ترتیب ۴۰/۱۲ روز در دمای ۲۵ °C و ۳/۷۱ روز در دمای ۳۵ °C بود. نرخ ذاتی افزایش جمعیت (*r*) *A. bambawali* در سه دمای ۲۵، ۳۰ و ۳۵ درجه سلسیوس به‌ترتیب ۰/۱۱۹۲، ۰/۱۵۹۹ و ۰/۲۱۴۲ بر روز بود. نرخ خالص تولیدمثل در سه دمای مذکور به‌ترتیب ۳۸/۰۴، ۵۵/۳۰ و ۸۱/۲۲ تخم/ فرد محاسبه شد. میانگین طول دوره یک نسل زنبور *A. bambawalei* از ۲۰/۵۲ روز در دمای ۳۵ °C تا ۳۰/۵۲ روز در دمای ۲۵ °C متغیر بود. این نتایج نشان می‌دهد که زنبور پارازیتوئید *A. bambawalei* به‌عنوان یک عامل کنترل بیولوژیک احتمالاً در دمای ۳۵ درجه سلسیوس نسبت به دماهای ۲۰ و ۲۵ درجه سلسیوس کارایی بیش‌تری دارد.

واژگان کلیدی: کنترل بیولوژیک، Chalcidoidea، جدول زندگی، شپشک، پارازیتیسم