Effect of temperature on life table parameters of *Eretmocerus delhiensis* (Hym.: Aphelinidae), a parasitoid of *Neomaskellia andropogonis* (Hem.: Aleyrodidae)

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Abstract

Development, reproduction, and life table parameters of the parasitoid *Eretmocerus delhiensis* Mani (Hymenoptera: Aphelinidae) parasitizing sugarcane whitefly, *Neomaskellia andropogonis* Corbett (Hemiptera: Aleyrodidae) were studied at 20, 25, 30 and 32°C, 45±5% RH, and 12: 12 h (L:D). The developmental time of egg to adult stage, decreased from 24.2±0.46 days at 20°C to 10.7±0.33 days at 32°C. An average of 250 degree-days was required to complete development above the lower threshold temperature (11.25°C). Preimaginal survivorship was 77.76±0.41, 82.33±0.38, 74.99 ±0.37, and 59.45±1.07% at 20, 25, 30, and 32°C, respectively. The mean fecundity of *E. delhiensis* was 65.66±1.48, 82.80±3.24, 18.93±0.60, and 8.46±0.49 eggs at 20, 25, 30, and 32°C, respectively, and had a mean longevity of 23.80±0.55, 17.33±0.54, 6.66±0.28, and 4.43±0.22 days at the same four temperatures. The intrinsic rate of population increase (r_m) ranged from 0.156±0.01 to 0.234±0.02, with the highest value recorded at 25°C. Our results revealed that 25°C is the optimum temperature for development and reproduction of *E. delhiensis*. These data can be used in supplementary studies to maximize the production of *E. delhiensis* from mass rearing facilities and to develop computer simulation models to predict *E. delhiensis* development plus population dynamics for release programs.

Keywords: Eretmocerus delhiensis, Neomaskellia andropogonis, Biology, Life table parameters, Sugarcane

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Introduction

Sugarcane (*Saccharum officinarum* L.) is grown as an important cash crop in the middle and south of Khuzestan province, southwest of Iran. In the last decade, the production of sugarcane has increased rapidly with over 90000 ha of sugarcane grown, yielding to 7.4 million tons harvest (Ahmadi et al., 2017). Sugarcane whitefly, *Neomaskellia andropogonis* Corbett (Hemiptera: Aleyrodidae), is one of the most important pests of sugarcane in this region (Askarianzadeh and Manzari, 2006; Minaeimoghadam et al., 2009, 2010; Malekmohammadi et al., 2013). Whitefly nymphs and adults suck the cell sap, mostly from the lower surface of the leaves. Production of honey dew by nymphs and development of sooty molds reduce the yield of sugarcane (Askarianzadeh, 2011).

Recent outbreaks of sugarcane whitefly in Khuzestane sugarcane fields have caused serious damages to sugarcane leaves (Askarianzadeh and Manzari, 2006; Minaeimoghadam et al., 2009, 2010). The extremely rapid rate of increase and protected location of *N. andropogonis* on the underside of sugarcane leaves renders the chemical control in the field unsuccessful (Dittrich et al., 1990). Furthermore, application of chemical insecticides may disrupt the already existing and very efficiently used biological control programs against stalk borers such as *Sesamia cretica* and *Sesamia nonagrioides*. Review of literature on the natural enemies of whiteflies has indicated that parasitoids belonging to the family Aphelinidae are the most promising candidates for biological control of these pests (Gerling, 1990; Onillon, 1990). According to previous studies, *Encarsia inaron* (Walker) and *Eretmocerus delhiensis* Mani proved to be common parasitoids associated with *N. andropogonis* on sugarcane in the region (Minaeimoghadam et al., 2010; Malekmohahamadi et al., 2012; Khadempour, 2014).

Eretmocerus delhiensis is a thelytokous parasitoid, which similar to other species in the genus *Eretmocerus* (Rose and Zolnerowich, 1997), oviposit externally under the nymphal host. After hatching, the first instar penetrates through the host cuticle, feeds, and pupates inside the whitefly puparium. Some studies have addressed the biology of *E. delhiensis* parasitizing *Trialeurodes vaporariorum* Westwood (Ebrahimifar et al., 2016; Ebrahimifar et al., 2017). However, there is no detailed bionomic study over *E. delhiensis* on *N. andropogonis*. On the other hand, many factors such as temperature influence the biological attributes of a parasitoid. In this study, the effects of different constant temperatures on development, longevity, and reproduction of *E. delhiensis* were investigated. Such data on thermal biology of *E. delhiensis* could be useful for predicting its phenology and population dynamics in the field as well as for optimizing mass rearing under laboratory conditions.

Materials and methods

Whitefly and parasitoid colony

Adult sugarcane whitefly, *N. andropogonis*, was collected from sugarcane plants during October 2012 at Debal Khazai sugarcane agroindustry. The whiteflies were reared continuously on the foliage of sugarcane plants (cultivar CP-69) bearing approximately 4-6 leaves. The infested plants were kept in wooden cages (120×120×60 cm) covered with nylon mesh of 120 µm aperture. The cages were maintained in the laboratory at 16-25°C, 45±5 % RH, and a photoperiod of 12:12 (L:D)h. Old and damaged sugarcane plants were replaced by new ones as needed. A

laboratory colony of *E. delhiensis* was initiated with adults collected from the same sugarcane field in November 2012. The parasitoids were reared on different nymphal stages of *N. andropogonis* grown on sugarcane leaves. The sugarcane plants and parasitoids were kept in cages similar to those described for sugarcane whitefly (16- 25 °C, 40-50 % RH and photoperiod of 12:12 L:D) under laboratory conditions. New sugarcane plants with leaves infested with different nymphal stages of sugarcane whitefly were transferred into the cages every week. These cages were also kept in the laboratory under similar conditions mentioned above.

Developmental time and survival of immature stages

In order to obtain the third nymphal stage of sugarcane whitefly, a group of 30-50 adult female whiteflies were placed in clip cages (Lewis, 1973) attached to the lower surface of sugarcane leaves for a 24 h oviposition period. The whiteflies were removed after 24 h and plants harboring eggs were maintained under laboratory conditions for about 12 days until all insects had reached the third nymphal instar (16-25°C, 40-50 % RH and photoperiod of 12:12 L:D). Preliminary studies showed that *E. delhiensis* would prefer the third nymphal stage of *N. andropogonis*. Two to three *E. delhiensis* females were introduced into the clip cages and allowed to oviposit in *N. andropogonis*. Wasps were removed after 24 h and plants harboring parasitized nymphs were transferred into the growth chamber, at four constant temperatures (20, 25, 30 and 32±1°C and a photoperiod of 12:12 (L:D). Relative humidity within the incubator varied from 40 to 50%, and light intensity was 1800 lux. The parasitized nymphs could easily be recognized by their brown color. The development of parasitoid was monitored via a dissecting microscope until adult emergence. The duration of immature stages and survivorship were recorded on a daily basis. The survivorship was calculated as the proportion of emerged parasitoids compared to the total number of parasitized nymphs.

Adult longevity and fecundity

The longevity and fecundity of *E. delhiensis* were studied by confining newly emerged (<24h) individual females (obtained from developmental experiment) in the clip cages on sugarcane leaves. The leaves were infested with at least 50 sessile third nymphal stages of *N. andropogonis*. Every 24 h, parasitoids were transferred by a mini aspirator to another *N. andropogonis* infested leaf, until the female parasitoid died. Parasitized *N. andropogonis* were checked daily until the last *E. delhiensis* had emerged. The daily and total number of parasitized *N. andropogonis* plus longevity of adult *E. delhiensis* were recorded. These experiments were also conducted in temperature controlled cabinets.

Data analysis

The lower threshold temperature for development was estimated using a linear regression equation, X intercept method. The parameter t (thermal threshold) and DD (thermal constant) were derived from the regression equation as follows: Y= a+bX, where Y denotes the reciprocal of the developmental duration in days (the developmental velocity= developmental rate= 1/developmental time), X represents the temperature in °C, "a" and "b" reflects the parameters of the linear regression (Campbell et al., 1974). From this, the lower developmental threshold (t), i. e. the temperature when development ceases can be estimated: t= -a/b. The number of degree-days (DD) required for development were calculated using equation: DD= 1/b.

To compare the reproductive output under ideal conditions in the laboratory, net

reproductive rate (R_0), intrinsic rate of increase (r), finite rate of increase (λ), and other population parameters were calculated according to method of Brich (1948) and Carey (1982) using a statistical Jacknife method (Maia et al., 2000). The R_0 was estimated by $\sum l_x m_x$, where l_x refers to the proportion of females surviving to day x and m_x denotes the mean number of female progenies produced during day x. Since males of *E. delhiensis* are rare (Khadempour, 2014), the sex ratio of 1 female: 0 male was used to calculate life table parameters. The r_m value was estimated by selecting values of r which would satisfy the expression $\sum e^{-r\, l_x\, m_x} = 1$.

Temperature effects on development time and survival of pre-adults as well as longevity and fecundity were determined via analysis of variance (ANOVA). The analysis was performed using SAS software (SAS Institute, 1997). The means were compared using Tukey test. Data for percentage survival were transformed (Arcsine-based) before analysis.

Voucher specimen of *N. andropogonis* and *E. delhiensis* are available at Department of Plant Protection, Faculty of Agriculture, Shahid Chamran University of Ahvaz, Ahvaz, Iran.

Results

Development time

The developmental period of *E. delhiensis* reared on *N. andropogonis* at constant temperatures revealed an inverse relationship between the duration of developmental time and temperature to which they were subjected (Table 1). Analysis of variance indicated significant differences ($F_{3,151}$= 261.8; P<0.0001) in developmental duration across the temperatures examined. The adult stage was attained by *E. delhiensis* reared at all temperature regimes. The mean duration from egg to adult ranged from 24.2 days at 20°C to 10.17 days at 32°C. The rate of development was about twice faster at 30°C than at 20°C. The developmental period of longest duration was 29 days and was recorded for individuals reared at 20°C.

The lower temperature threshold for the development of *E. delhiensis* was calculated to be 11.25°C (Table 2). Based on this threshold, an average of 250 degree-day was needed for an *E. delhiensis* female to complete the development from egg- to- adult (Table 2).

Table 1. Mean (± SE) developmental time and survival of the immature stages of *Eretmocerus delhiensis* parasitizing *Neomaskellia andropogonis* on sugarcane at different constant temperatures

Stages	Temperature (°C)			
	20	25	30	32
Developmental time (d)	24.2± 0.46 a	16.9± 0.34 b	13.83 ± 0.32 c	10.17 ± 0.33 d
(Number) Range	(38) 20-29	(41) 13-20	(34) 10-16	(39) 7-13
Survival (%)	77.76 ± 0.41 b	82.33 ± 0.38 a	74.99 ± 0.37 b	59.45 ± 1.07 c
(Number) Range	(145) 108-116	(138) 110-115	(149) 107-113	(153) 84-92

Means in each row followed by the same letter were not significantly different at the 0.05 level when tested by Tukey test.

Table 2. Temperature requirement (DD), weighted regression for developmental rate (Y) against temperature and threshold temperature (t) of *Eretmocerus delhiensis*, parasitizing *Neomaskellia andropogonis*.

Temperature (°C)	Number observed	Mean developmental period (days ± SE)	Rate of development	Degree day (DD)
20	38	24.2 ± 0.46 a	0.041	225.786
25	41	16.9 ± 0.34 b	0.059	242.177
30	34	13.83 ± 0.32 c	0.072	267.333
32	39	10.17± 0.33 d	0.098	216.926
Regression	Y= -0.045 + 0.004 X	R^2= 0.907	Mean DD= 250	*t* = 11.25

Means in the column followed by the same letter were not significantly different at the 0.05 level when tested by Tukey test.

Table 1 reports the pre-imaginal survival of *E. delhiensis* on *N. andropogonis* at four constant temperatures. Pre-imaginal survival was significantly affected by temperature ($F_{3,584}$= 244.8; P<0.0001). However, there were no significant differences in the average survival of *E. delhiensis* at 20 and 30°C.

The adult longevity of *E. delhiensis* decreased as temperature increased (Table 3). On average, they lived for 23.80, 17.33, 6.66, and 4.43 days at 20, 25, 30, and 32°C, respectively. ANOVA demonstrated that these differences in longevity were significant at the different temperatures ($F_{3,119}$= 455.77; P<0.0001). The maximum and minimum longevities of *E. delhiensis* were 29 and 2 days at 20 and 32°C, respectively.

ANOVA indicated significant overall temperature effects on mean total fecundity ($F_{3,119}$= 387.83; P<0.0001) and mean daily fecundity ($F_{3,119}$= 41.79; P<0.0001). The highest egg production occurred at 25°C (Table 3). At this temperature, the maximum number of eggs produced by an individual female was 107. At temperatures above 25°C, the fecundity of *E. delhiensis* diminished significantly.

The values for the different life table parameters are presented in Table 4. The net reproductive rate (R_0) increased at 25°C and then decreased at 30 and 32°C. (Table 4). The mean generation time (T) declined gradually with the increase of temperature, while the intrinsic rate of natural increase (r) rose at 25°C and then dropped at 30 and 32°C.

Table 3. Mean (± SE) longevity and fecundity of *Eretmocerus delhiensis* parasitizing Neomaskellia andropogonis at different constant temperatures (n= 30).

Life table parameters	Temperature(°C)			
	20	25	30	32
longevity (d)	23.80±0.55 a	17.33±0.54 b	6.66±0.28 c	4.43±0.22 d
Range	18-29	10-23	4-9	2-6
Total fecundity	65.66±1.48 b	82.80±3.24 a	18.93±0.60 c	8.46±0.49 d
Range	49-82	46-107	13-25	4-13
Average eggs/day	2.79±0.08 b	4.95±0.29 a	3.011±0.18 b	2.04±0.20 c
Range	0-4	3-10	2-7	1-5

Means in each row followed by the same letter were not significantly different at the 0.05 level when tested by Tukey test.

Table 4. Demographic parameters for *Eretmocerus delhiensis* parasitizing *Neomaskellia andropogonis* at different constant temperatures.

Life table parameters	Temperature (°C)			
	20	25	30	32
Intrinsic rate of increase (r_m)	0.156 ± 0.01 d	0.234±0.02 a	0.20±0.03 b	0.18±0.01 c
Net reproductive rate (R_0)	54.26 ±0.22 b	69.04±1.61 a	14.85±0.19 c	6.21±0.07d
Finite rate of increase (λ)	1.169±0.02 b	1.26±0.05 a	1.22±0.03 c	1.20±0.05 d
Mean generation time (T)	25.47±0.39 a	18.08±0.32 b	13.38±0.26 c	9.84±0.29 d
Doubling time (DT)	4.42±0.12 a	2.96±0.06 d	3.44±0.12 c	3.73±1.05 b

Means in each row followed by the same letter were not significantly different at the 0.05 level when tested by Tukey test.

Discussion

The developmental time of *E. delhiensis* on *N. andropogonis* was 16.9 days at 25°C. The developmental time of *E. delhiensis* parasitizing *T. vaporariorum* was reported to be 15.03 at 25°C (Ebrahimifar et al., 2017), which is close to our findings. Furthermore, similar results have been reported for other thelytokous *Eretmocerus* species. Ardeh (2005) observed developmental times of 16.1, 15.6, and 15.4 days on tomato, poinsettia, and gerbera, respectively, for thelytokous population of *Eretmocerus mundus* on *Bemisia tabaci* (Gennadius) at 25°C. McAuslane and Nguyen (1996) reprted 16.4 days for developmental duration of thelytokous *Eretmocerus rui* on *B. tabaci* (B strain) at 24- 27°C. In a comparable study, Sengonca et al. (1994) obtained a total development time of 17 days for thelytokous *Eretmocerus debachi* Rose and Rosen on *Parabemisia myricae* (Kuwana) at 25°C. In an experiment with thelytokous population of *E. mundus* parasitizing *B. tabaci*, Ghahari et al. (2005) found the mean developmental time as 16.4 days at 25°C.

The lower temperature threshold of 11.25°C found in the present study for development of *E. dehiensis* female on *N. andropogonis* has been very similar to the threshold of 11.5°C for the development of arrhenotokous *E. mundus* female on *B. argentifolii* on poinsettia (Qiu et al., 2004). The mean number of degree-days required by *E. delhiensis* to complete its development was 228.61 DD. This is also similar to that of Qui et al. (2004) for sexual *E. mundus* female (230 DD) on poinsettia.

The longevity of *E. delhiensis* reported to be 5.71 days parasitizing greenhouse whitefly, *T. vaporariorum* at 25°C (Ebrahimifar et al., 2016, 2017) which is far lower than our findings (17.33 days) at the same temperature. The longevity of thelytokous *E. debachi* on *P. myricae* at 25°C was reported to be 17 days (Sengonca et al., 1994), which is similar to the current results. However, a shorter longevity of 8.4 days was reported by McAuslane and Nguyen (1996) for asexual *E. uri* on *B. tabaci* (B strain) at 24-27°C, 9.2, 7.2, and 8.3 days by Ardeh (2004) for thelytokous *E. mundus* (Australian population) on *B. tabaci* on tomato, poinsettia, and gerbera, respectively, at 25°C and 7.6 days by Ghahari et al. (2005) for asexual *E. mundus* (Iranian population) on *B. tabaci* on cotton at 25°C. In an experiment with thelytokous population of *Eretmocerus eremicus* parasitizing *B. tabaci* on cotton, Powell and Bellows (1992) found the mean longevity of 8.43 days at 29°C, which is longer than our result (6.66 days) at 30°C.

The mean total fecundity of *E. delhiensis* was 82.8 eggs on sugarcane whitefly at 25°C. This value has been very higher than the value of 17.43 offspring reported for this parasitoid on *T. vaporariorum* at the same temperature (Ebrahimifar et al., 2016, 2017). Nevertheless, our value of 82.80 eggs is in line with the results of Sengonca et al. (1994), McAuslane and Nguyen (1996), as well as Ghahari et al. (2005), who reported 70, 92.8, and 81.7 eggs for thelytokous *E. debachi*, *E. rui*, and *E. mundus* (Iranian population), respectively, at similar temperature (25°C). In contrast, Ardeh (2004) reported 54.6, 28.6, and 19 eggs for asexual *E. mundus* (Australian population) parasitizing *B. tabaci* on tomato, poinsettia, and gerbera, respectively, at similar temperature. At 29°C, Powell and Bellows (1992) reported means of 41 and 47 eggs laid by thelytokous *E. ermicus* parasitizing *B. tabaci* on cotton and cucumber, respectively, which is higher than our results (18.93 eggs) at 30°C. In a laboratory experiment with thelytokous *Eretmocerus mundus* and *Eretmocerus queenslanensis* (Naumann) on *B. tabaci*, DeBarro et al. (2000) found total fecundity of 138 and 130 eggs, respectively, on rockmelon at 22-30°C, which is far larger than our results.

The intrinsic rate of increase (r_m) of *E. delhiensis* was 0.23 d^{-1} on *N. andropogonis* at 25°C. Ebrahimifar et al. (2016) reported the *r* value of 0.16 for *E. delhiensis* parasitizing *T. vaporariorum* at the same temperature, which is lower than our findings. At 25°C, Ardeh (2004) reported r of 0.23 and 0.20 for thelytokous population of *E. mudus* parasitizing *B. tabaci* on tomato and poinsettia, respectively, which is favorably comparable to the results in the present study (r = 0.234) at the same temperature. However, other laboratory studies have reported a variety of *r* values for other thelytokous *Eretmocerus* species. Sengonca et al. (1994) reported the *r* value of asexual *E. debachi* as 0.19 female/female/day at 25°C. Powell and Bellows (1992) obtained 0.160 and 0.211 for *r* at 29°C for thelytokous population of *E. eremicus* on *B. tabaci* on cotton and cucumber, respectively. Furthermore, the value of intrinsic rate of increase of *E. inaron*, another natural parasitoid of *N. andropogonis* in the Khuzestan province, was reported 0.11, 0.20, 0.18, and 0.12 at 20, 25, 30, and 32°C, respectively (Malekmohammadi et al., 2012), which is lower than the *r* values of *E. delhiensis* obtained in the current study on the same host and the same range of temperatures.

In conclusion, the results of the current study have provided useful data for mass rearing of *E. delhiensis*. Our findings also indicated that *E. delhiensis* could be a useful biological control agent against *N. andropogonis* particularly at 25°C. However, for a more precise assessment of the impact of this thelytokous parasitoid on its host, additional studies on other biological parameters, such as functional and numerical responses, etc. are required, especially under natural conditions where the heterogeneity of environment may affect and perhaps modify parasitoid and host interactions.

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تأثیر دما بر پارامترهای جدول زندگی زنبور *Eretmocerus delhiensis* (Hym.: Aphelinidae)، پارازیتوئید *Neomaskellia andropogonis* (Hem.: Aleyrodidae)

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چکیده

رشد، تولیدمثل و پارامترهای جدول زندگی زنبور پارازیتوئید *Eretmocerus delhiensis* Mani روی سفید بالک نیشکر، *Neomaskellia andropogonis* Corbett در دماهای ۲۰ ، ۲۵، ۳۰ و ۳۲ درجه سلسیوس مطالعه شد. دوره‌ی رشد از تخم تا حشره کامل از ۰/٤٦±۲٤/۲ روز در ۲۰ درجه به ۰/۳۳±۱۰/۷ روز در ۳۲ درجه سلسیوس کاهش یافت. در دماهای بالاتر از آستانه پائین دمایی (۱۱/۲۵ درجه سلسیوس)، به طور میانگین به ۲۵۰ روز- درجه برای کامل شدن دوره‌ی رشد نیاز بود. میزان بقاء مراحل نابالغ در چهار دمای ۲۰، ۲۵، ۳۰ و ۳۲ درجه سلسیوس به ترتیب ۰/٤۱±۷۷/۷٦، ۰/۳۸±۳۷/۳۳، ۰/۸۲±۷٤/۹۹ و ۱/۰۷±۵۹/٤۵ درصد بود. در دماهای مذکور پارازیتوئیدهای ماده *E. delhiensis* به طور طور میانگین ۱/٤۸±۵٦/٦٦، ۳/۲٤±۸۲/۸۰، ۹۳/٦۰±۱۸/۰ و ۰/٤۹±۸/٤٦ تخم گذاشتند و میانگین عمر آنها به ترتیب ۰/۵۵±۲۳/۸۰، ۰/۵٤±۱۷/۳۳، ۰/۲۸±٦/٦٦ و ۰/۲۲±٤/٤۳ روز بود. نرخ ذاتی افزایش جمعیت دامنه‌ای از ۰/۰۱±۰/۱۵٦ تا ۰/۰۲±۰/۲۳٤ ماده/ ماده/ روز داشت و بیشترین مقدار در ۲۵ درجه سلسیوس ثبت شد. در بررسی‌های تکمیلی می‌توان از این اطلاعات برای تولید انبوه زنبور *E. delhiensis* و همچنین توسعه مدل‌های شبیه‌سازی با هدف افزایش کارایی در رهاسازی این پارازیتوئید استفاده نمود.

کلیدواژه‌ها: *Eretmocerus delhiensis* ، *Nepmaskellia andropogonis*، زیست شناسی، پارامترهای جدول زندگی، نیشکر