Life table parameters of the coccinellid *Hyperaspid polita*, a native predator in Iran, feeding on the invasive mealybug *Phenacoccus solenopsis*

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**Abstract**

*Hyperaspid polita* Weise (Coleoptera: Coccinellidae) is one of the most important predators of the cotton mealybug, *Phenacoccus solenopsis* Tinsley (Sternorrhyncha: Coccoidea: Pseudococcidae), in southern Iran. The development, survivorship, longevity, reproduction, and life table parameters of this predator were evaluated at 25, 30, and 35 ± 1 °C, 65 ± 5% RH and a photoperiod of 14:10 D. The duration of total pre-adult stage in males and females decreased from 32.63 and 30.06 at 25 °C to 19.96 and 19.37 days at 35 °C, respectively. The oviposition period of females was significantly affected by temperature that was, 47.73, 68.66 and 27.65 days with average egg production of 207.37, 505.50, and 151.03 at 25, 30, and 35 °C, respectively. According to the age-stage, two-sex life table, the highest values of the intrinsic rate of increase \( \lambda \) were obtained at 30 (0.112 d\(^{-1}\)) and 35 °C (0.120 d\(^{-1}\)) with no significant difference. The finite rate of increase (\( R_0 \)) was the highest at 30 (1.130 d\(^{-1}\)) and 35 °C (1.146 d\(^{-1}\)) with no significant difference. The net reproductive rate was the highest at 30 °C (\( R_0 = 204.240 \) offspring) and the mean generation time was shortest at 35 °C (T = 29.87 d). The results indicate that suitable temperature for population development and fecundity of *H. polita* is around 30 °C, which could be a result of adaptation of this coccinellid predator to the warm climate of southwestern Iran.

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**Introduction**

The cotton mealybug, *Phenacoccus solenopsis* Tinsley (Sternorrhyncha: Coccoidea: Pseudococcidae), is an invasive pest species damaging > 200 plant species in the tropics and Subtropics (Hodgson et al., 2008; Fand and Suroshe, 2015). It is considered the dominant pest in most cotton-growing areas in Asia in recent years causing notable damage to cotton production in these areas (Abbas et al., 2005; Dhawan et al., 2007; Dutt, 2007; Jhala et al., 2008). In recent years, *P. solenopsis* has been reported in southern Iran on Chinese hibiscus shrubs, *Hibiscus rosa-sinensis* L. with high population, and also on other hostplants such as *Solanum lycopersicum* and *Lantana camara* (Moghaddam and Bagheri, 2010; Mossadegh et al., 2012a). The mealybug causes symptoms such as distortion, bushy shoots, crinkled and/or twisted bunchy leaves and stunted plants in infested hosts during the vegetative phase, and in severe infestation, the plant is completely destroyed. The mealybug secretes honeydew on which sooty mold grows, and decreases photosynthesis and marketability of crops (Culik and Gullan, 2005; Kranthi et al., 2009; Nagrare et al., 2011). Therefore, there is an urgent need to develop effective control strategies against this insect pest.

Several natural enemies such as *Aenasius bambawalei* Hayat, *Nephus arcaurus* Kapur, *Hyperaspid polita* Weise and *Dicrodiplosis manihoti* Harrison have been recorded for *P. solenopsis* in southern Iran (Fallahzadeh et al., 2013; Mossadegh et al., 2012b, 2013). The native predator coccinellid *Hyperaspid polita* Weise, 1885 has been reported as an important natural enemy of *P. solenopsis* and other scale insect pests from several localities in southern Iran (Koohpayehzadeh Isfahany and Mossadegh, 1993; Fallahzadeh et al., 2013; Mossadegh et al., 2012b), Pakistan, Turkey, Lebanon, and eastern Mediterranean coastal regions (Alizadeh et al., 2013). Khodaman (1993) following some experimental and field investigations on the biology of the ladybird predators of *Nipaecoccus viridis* (Newstead) in south-west Iran concluded that *H. polita* is a more suitable predator than other coccinellids. However, little is known about the development, survivorship, and life table parameters of this species.

A thorough understanding of a predator's biological characteristics such as growth rate, survivorship and fecundity is necessary for its mass rearing and utilization. One of the main factors influencing the biology, ecology and dynamics of pests and their natural enemies is...
temperature (Jervis and Copland, 1996). Rate of development in ladybirds is affected by the environmental temperature, and an appropriate temperature increases the rate of development and decreases developmental periods (El habi et al., 2000). Temperature is also an important factor for insect population establishment and success in the field (van Lenteren et al., 2006). Therefore, improving existing knowledge of the effects of temperature on H. polita development is necessary for mass rearing of the insect and its application as a natural predator.

In the present study, data regarding the survival, fecundity, and life table parameters of H. polita on the invasive P. solenopsis at prevailing temperature range in southern Iran were collected and analyzed based on the age-stage, two-sex life table.

**Materials and methods**

**Insect rearing**

*Hyperaspidis polita* adults used in this study were originally collected from the Chinese hibiscus shrub infested by *P. solenopsis* at Shahid Chamran University of Ahvaz, south-west Iran (31° 18' 14" N, 48° 39' 29" E, 21 m elevation) in May 2014. Ladybirds were transferred to ventilated plastic containers (27 × 12 × 20 cm) with small branches of Chinese hibiscus infested with *P. solenopsis* as a stock colony and maintained in a growth chamber (temperature 25 ± 1 °C, relative humidity 65 ± 5% and photoperiod of 14 L:10 D). Phenacoccus solenopsis were collected daily from those shrubs and placed in containers. Every 5 months, 30 adults of *H. polita* were collected from the field and mixed with the stock colony to maintain genetic variability. Identity of both coccinellid and mealybug were confirmed by taxonomists.

**Life table study**

The experiment was conducted at three constant temperatures (25 ± 1, 30 ± 1, and 35 ± 1 °C), 65 ± 5% relative humidity and 14 L:10 D using a set of incubators. Before initiating the life table study, 40 adult pairs of *H. polita* were obtained from the stock colony and maintained at each temperature for one generation. Coccinellid eggs deposited within a 24-h period were collected for the life table study at each temperature. Every day, newly emerged larvae were caged individually into transparent plastic containers (4 cm × 7 cm × 9 cm) covered with fine nylon netting for ventilation. Cotton mealybugs of mixed immature stages were supplied at overabundance to each larva on the hibiscus leaf over moistened cotton wool. Developmental periods in males and females decreased as temperature increased from 25 to 35 °C. However, there were no significant differences between 25 and 30 °C for 2nd instar, as well as 30 °C, and 35 °C for prepupa stage. Total preadult period between males and females was significantly different at 25 °C and 30 °C. Temperature had also significant (*P < 0.05*) effect on egg incubation period. The average incubation period decreased from 5.24 days at 25 °C to 3.37 days at 35 °C (Table 1).

The highest preadult survival was recorded at 30 °C, but significantly lower survival (32%) was recorded at 35 °C (Table 1). However, there was no significant difference in survival rates between 30 °C and 25 °C (51%). Age-stage-specific survival rate (*lx*) represents the probability that a newborn egg would survive to age *x* and stage *j* (Fig. 1). Due to the variable developmental rates among individuals, significant overlaps between stages were observed under all conditions accounted in the age stage, two-sex life table. The probability that a newly laid egg would survive to the adult stage increased from 25 °C (0.34, 0.32) to 30 °C (0.40, 0.34) and decreased at 35 °C (0.18, 0.18) for females and males, respectively.

The daily mean number of offspring produced by individual *H. polita* of age *x* and stage *j* per day is shown with the age-stage fecundity (*fxj*) in Fig. 2. Since only adult females produce offspring, there is only a single curve *fxa* (i.e. the adult female is the 8th developmental stage).

Age-specific survival rate (*lx*) curve describes the change in survival rate of the cohort with age (Fig. 2). This parameter is temperature-dependent and decreased with increased temperature. In contrast, the percentage of time females spent ovipositing increased with increase in temperature. The highest peaks for age-stage specific fecundity (*fxa*), age-specific fecundity (*mx*), and age specific maternity (*lx mx*) were recorded at 30 °C (Fig. 2).

**Adult longevity, fecundity and offspring’s sex ratio**

The adult preoviposition period, APOP; total preoviposition period, TPOP and oviposition period were all significantly (*P < 0.05*) reduced with an increase in temperature from 25 to 35 °C (Table 2).
oviposition period varied from 27.65 to 68.66 days and was occasionally interrupted by 1 to 3 days without egg laying.

The total fecundity (number of eggs produced per female during the oviposition period) was significantly \((P < 0.05)\) affected by temperature. Mean total fecundity ranged from 151.03 eggs at 35 °C to 505 eggs at 30 °C. Maximum daily fecundity was 20, 30 and 23 eggs at 25, 30 and 35 °C, respectively (Table 2).

Mean longevity ranged from 151.03 eggs at 35 °C to 505 eggs at 30 °C. Maximum daily fecundity was 20, 30 and 23 eggs at 25, 30 and 35 °C, respectively (Table 2).

The longevity of both males and females was significantly affected by temperature and was observed to be greatest at 25 °C. Therefore, longevity significantly decreased with an increase in temperature. Mean longevity was significantly higher in females than in males. Sex ratio was significantly \((P < 0.0001)\) affected by temperature as this variable was highest (64%) at 35 °C and lowest (53%) at 30 °C (Table 2).

**Life table parameters**

The intrinsic rate of increase \((r_m)\) increased with increasing temperature, the highest value \((0.120 \text{ d}^{-1})\) was observed at 35 °C, and the
Table 2
Mean (±SEM) preoviposition period (APOP), total preoviposition period (TPOP), oviposition period, adult longevity and fecundity of H. polita fed on P. solenopsis at three different constant temperatures.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Statistic parameters</th>
<th>25 °C</th>
<th>30 °C</th>
<th>35 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adult preoviposition (days)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>APOP</td>
<td>7.36 ± 1.14ab</td>
<td>3.39 ± 0.20b</td>
<td>1.86 ± 0.15b</td>
</tr>
<tr>
<td></td>
<td>TPOP</td>
<td>32.53 ± 1.14a</td>
<td>27.38 ± 0.43a</td>
<td>21.24 ± 0.47b</td>
</tr>
<tr>
<td></td>
<td>Oviposition days (days)</td>
<td>47.73 ± 3.59a</td>
<td>68.66 ± 1.63a</td>
<td>27.65 ± 1.20b</td>
</tr>
<tr>
<td></td>
<td>Fecundity (egg/female)</td>
<td>207.37 ± 24.22b</td>
<td>505.50 ± 32.44a</td>
<td>151.03 ± 15.88b</td>
</tr>
<tr>
<td></td>
<td>Sex ratio (offspring)</td>
<td>60%B</td>
<td>53%B</td>
<td>64%B</td>
</tr>
<tr>
<td></td>
<td>Maximum daily fecundity</td>
<td>20</td>
<td>30</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Adult longevity (days)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>121.87 ± 8.23a</td>
<td>84.19 ± 4.33aa</td>
<td>39.85 ± 2.07aa</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>83.48 ± 9.10a</td>
<td>52.79 ± 4.46aa</td>
<td>22.65 ± 2.28a</td>
<td></td>
</tr>
</tbody>
</table>

⁎ Values in rows followed by the same small letter are not significantly different using the paired bootstrap test at 5% significance level.
** Values in columns followed by the same capital letter are not significantly different using the paired bootstrap test at 5% significance level.

Age-stage specific life expectancy

The age-stage-specific life expectancy \( e_{xj} \) is the lifespan remaining for an individual of age \( x \) and stage \( j \). The \( e_{xj} \) of a newborn \( (e_{0j}) \) is exactly the same as the mean longevity. The age-stage specific life expectancies \( e_{xj} \) of H. polita at three experimental temperatures are shown in Fig. 3. The maximum life expectancy of all stages of H. polita was recorded at 25 °C (Fig. 3). Life expectancy decreased gradually with age, since the study was conducted in the laboratory and thus unaffected.

Age-stage reproductive value

Fisher (1930) defined the reproductive value \( v_{xj} \) as the contribution of an individual to the future population. The age stage reproductive value \( v_{xj} \) of H. polita describes the contribution of an individual of age \( x \) and stage \( j \) to the future population at different temperatures (Fig. 4). The reproductive value of a newborn \( (v_{0j}) \) is exactly equal to the finite rate of increase. The negative effect of a decrease in temperature on reproduction in H. polita can be observed in the age-specific reproductive curve \( v_{xj} \). The maximum reproductive peak of females reared at 25 °C occurred much later than that of females reared at 30 °C and 35 °C.

Discussion

Insects have an optimum temperature range for development (Huffaker et al., 1999), and their survival and development are significantly impacted when the temperature is below or above this range (Huang et al., 2008). Even though insects are not always subject to constant temperatures in nature, a controlled study can provide a valuable insight into the population dynamics of a particular species (Summers...
et al., 1984). Our study of temperature effects on fecundity and population growth of H. polita showed that duration of preadult stages exhibited a temperature dependent trend in which shorter developmental durations were observed at higher temperatures. Long preadult duration of H. polita was found to be similar to that of other members of the genus Hyperaspis: H. notata Muls. reared on Phenacoccus herreni Cox & Williams (Dreyer et al., 1997), H. jucundata (Muls.) reared on P. manihoti (Nsiama She et al., 1984), H. pantherina Fürsch fed an an ortheziid scale insect pest (Booth et al., 1995) and H. maindroni Sicard reared on P. solenopsis (Fand et al., 2010). The highest reproductive rate of H. polita was also found at 30 °C which was similar or higher than the mean lifetime fecundity of the other mentioned congeneric species such as H. notata (534 eggs; Dreyer et al., 1997), H. jucunda (456 eggs; Nsiama She et al., 1984), H. maindroni (370.2 eggs; Fand et al., 2010), and H. pantherina (325 eggs; Booth et al., 1995).

According to our results, the preadult mortality percentage of H. polita in high temperature of 35 °C was lower than that reported for two strains of H. notata at 34 °C (100% and 99.9%) (Dreyer et al., 1997). It seems that H. polita is less sensitive to increasing temperatures up to 35 °C compared to other congeneric coccinellids.

H. polita adults lived longer than their congeneric species. Nsiama She et al. (1984) reported the longevity of female and male H. jucunda to be 101 and 100 d respectively, at 27 °C, while the values for H. maindroni were recorded as 72.4 and 60 (Fand et al., 2010). In all three species, female longevity decreased with increasing temperature. These findings are consistent with results observed in other species of Coccinellidae (Dreyer et al., 1997).

H. polita life expectancy indicated that adults reared at 25 °C could live >3 months, and at 35 °C >3 weeks. In natural environments, however, most populations are influenced by a variety of changing biotic and abiotic factors. For example, Moser and Obrycki (2009) concluded that intraguild predation occurs among coccinellid species and may affect their survival rates.

Previous studies did not examine the effect of temperature on life-table parameters of H. polita, but there are similar studies on other Hyperaspis species. Actually, it is difficult to compare demographic parameters between studies due to species differences, genetic variation, different rearing methods and other experimental conditions. However, the intrinsic rate of increase \((r_m)\) is the most appropriate demographic parameter for comparing different species or different conditions. This parameter \((r_m)\) is a good indicator of the temperature at which the growth of a population is most favourable, as it reflects the overall effect of temperature on development, survival and reproduction characteristics of a population. Based on our results, \(r_m\) increased with increasing temperature. The lowest developmental rate was observed at 25 °C, but the higher rates recorded at 30 and 35 °C with no significant differences. Dreyer et al. (1997) calculated the \(r_m\) for two Brazilian and Colombian strains of H. notata at 25, 30, 32 and 34 °C as 0.081 and 0.0744, 0.1024 and 0.1157, 0.0557 and 0.0757 as well as 0 day\(^{-1}\), respectively. The \(r_m\) of H. polita was much higher than those of H. notata at 34 °C. However, the \(r_m\) for H. polita at 25 and 30 °C lies within the range of earlier report for H. notata (Dreyer et al., 1997).

Fortunately, scale insect pests in southern Iran possess rich fauna of natural enemies capable of adapting to the dry and warm weather in this region (Asadeh and Mossadegh, 1993; Fallahzadeh et al., 2013; Mossadegh and Kochelli, 1993; Mossadegh et al., 2012b, 2013). In this study, different developmental stages of H. polita were observed in the hot weather conditions of Khuzestan province on leaves and twigs of Chinese hibiscus shrubs while feeding on P. solenopsis. It demonstrates that the native H. polita is adapted to warm temperatures of southwest Iran. On the other hand, Chinese hibiscus shrub has intensive plant canopy which contains less heat inside plant foliage, causing to reduce temperature inside the shrub and provide a better condition for the coccinellid activity in hot days of summer. Adaptation to warm condition could be very important for such natural enemies in southern Iran. For example, in biological control project of the mealybug Nipaecoccus viridis (New.) by the introduced Cryptolaemus montrouzieri Mul. in Khuzestan province, the coccinellid reproduction and activities were suppressed by increasing temperature in early summer (Mossadegh et al., 2008).

According to results obtained in this study, temperatures between 25 and 30 °C are optimal for population growth of H. polita as preadult survival significantly decreases at 35 °C (Khodaman (1993) reported similar results; when temperature exceeded 30 °C in summers, the population of H. polita suffers heavy loss in nature. To reach the maximum \(r_m\) and \(K_0\), 30 °C is the appropriate temperature for mass rearing of H. polita.

Conclusions

Our data of life table study of H. polita at different temperatures under controlled laboratory conditions recorded the biological potential of the development and fecundity of this species to be a native candidate for biological control of P. solenopsis in southern Iran. It could be a foundation for other studies on mass rearing programs and the establishment of management policies for scale insect pest control in the area. For practical applications, however, further studies on the field efficacy and behavior of H. polita as a biological control agent and the population growth of both predator and its prey under field conditions are needed to reach firm conclusions.

Acknowledgements

We express our sincere gratitude to Professor Dr. Hsin Chi as well as Dr. Sara Zarghami for their assistance in life table analyses. We are also
thankful to Dr. C.J. Hodgson and Dr. H. Fürsch for identifying the mealybug and the coccinellid species. This study was funded by the Shahid Chamran University of Ahvaz (grant #27176).

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