Comparative life table of Aphis craccivora (Hem.: Aphididae) on host plant, Robinia pseudoacacia under natural and laboratory conditions

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Abstract

The cowpea aphid, Aphis craccivora Koch, is an important pest of Robinia pseudoacacia Frisia. The life table parameters of A. craccivora were determined under natural (16–33°C and 32-89% RH) and laboratory (25±1°C, 70±5% RH) and a photoperiod of 16:8 h (L: D) conditions. The data were analyzed using the age-stage, two-sex life table theory. Each experiment was replicated 45 times for each condition. There were significant differences between the survivorship, fecundity and longevity of the A. craccivora in laboratory and natural conditions. Under natural conditions, A. craccivora had a significantly shorter nymphal developmental time, adult longevity and life span than those reared under laboratory condition. However, the intrinsic rate of increase (r), net reproductive rate (K), the finite rate of increase (i) and gross reproductive rate (GRR) in laboratory were higher than those obtained in the field except for higher mean generation time (T) resulted from field experiment. The results provide better understanding of the population dynamics of A. craccivora under field condition to effectively control the pest through integrated pest management (IPM) programs.

Keywords: Aphis craccivora, generation time, intrinsic rate of increase, life table parameters, natural condition

Introduction

Black locust, Robinia pseudoacacia Frisia, is a nitrogen-fixing leguminous tree that is widely planted in the temperate regions of North America, Europe and Asia for its resistance to many environmental stresses such as drought, low and high temperature, air pollutants and low fertility (Surles et al., 1989; Dini-Papanastasi & Panetsos, 2000). Therefore, R. pseudoacacia is an economically and ecologically important tree species in the world.

One of the most important pests of black locust is Aphis craccivora Koch (Hemiptera: Aphididae). The cowpea aphid, A. craccivora, is considered as a major pest of important economic crops like alfalfa, beans and...
cowpea in Asia, Africa and Latin America (Singh & Jackai, 1985; Pettersson et al., 1998). It can transmit plant pathogenic viruses (Coceano & Peressini, 1989; Chen et al., 1999). The early season injuries caused by this pest on *R. pseudoacacia* induce severe malformation of the newly established leaves (Rakhshani et al., 2005).

Understanding the factors affecting the aphid’s development and implementing this information into forecast models, may increase the efficacy and success of control methods (Kührt et al., 2006). Understanding the ecology of a pest and estimating the growth parameters and reproduction potential of insect population is an important issue for successful theoretical and applied population ecology and pest management programs (Soroushmehr et al., 2008). The life table provides an integrated and comprehensive description in details of development times, survival rates of each growth stage, fecundity and life expectancy of a population, and is often used by scientists as a method of projecting the growth of populations and predicting their sizes (Chi, 1990; Carey, 1993; Medeiros et al., 2000; Southwood & Henderson, 2000).

Population growth rate is a basic ecological characteristic that usually described as the intrinsic rate of increase (*r*), an estimate of population growth potential introduced by Birch (1948). Southwood (1966) demonstrated that the intrinsic rate of increase is the most practical life table parameter to compare the population growth potential of different species under specific climatic and nutritional conditions (Roy et al., 2003). The intrinsic rate of increase has been widely used as a bioclimatic index (Hulting et al., 1990).

Numerous studies have been intended to evaluate the effect of crop density on the population dynamics of *A. craccivora* (Farrell, 1976), relationship between *A. craccivora* and host plant odors and pheromones (Pettersson et al., 1998), its parasitoids (Johnson, 1959; Rakhshani et al., 2005), different species of ants (Katayama & Suzuki, 2002; 2003), and cloned stunt virus (Gutierrez et al., 1971; 1974) and presence of different endosymbiont on *A. craccivora* (Brady & White, 2013). The only study on life table and population parameters of *A. craccivora* was done on five cowpea varieties in laboratory condition by Obopile & Ostitute (2010).

*R. pseudoacacia* is an important ornamental tree in Iran. The main purpose of this study was to determine the impact of two different rearing conditions (natural and laboratory conditions) on the life table parameters of *A. craccivora* on black locust to construct precise predictions of the dynamics of its populations in the field.

**Materials and methods**

**Insect culture**

Leaves bearing apterous adults and different instars of *A. craccivora* were collected from *R. pseudoacacia* bushes on the campus of Faculty of Agricultural Sciences at the University of Guilan (Northern Iran) in 2013 and placed in a growth chamber at 25±1°C, 65±5% relative humidity (RH) and photoperiod of 16:8h (L:D).

**Life table study**

The colony of *A. craccivora* was maintained for two generations on *R. pseudoacacia*. Some adults of *A. craccivora* were released on *R. pseudoacacia* leaves for 24 h. This procedure allowed standardizing the age of newly born nymphs. Then, newly born nymphs of *A. craccivora* were placed separately on a *R. pseudoacacia* leaf in plastic Petri dishes (10 cm in diameter) with a hole in the center of the lid covered with fine nylon mesh for aeration. A layer of wet cotton padding, 0.5 cm-thick, lined the Petri dish, and the leaf was on the bottom of the Petri dish according to Madahi & Sahragard (2012) and Hosseini-Tabesh et al. (2015). Once leaves appeared to be discolored, they were replaced with fresh ones (usually daily). The aphid nymphs were placed in their natural position on the undersurface of the leaves in laboratory condition (25±1°C, 65±5% RH) (Liu & Meng, 1999). Nymphal development was recorded daily. After adult appearance, longevity and the number of produced nymphs by females were recorded daily.

A similar methodology was used to study the life table of *A. craccivora* in leaf cages in the field. Each Petri-dish had a hole in the center of the lid, and was covered with muslin for aeration. A hole was made through both the lid and the body of the Petri dish. The leaf cage was placed over the leaf with the stem of the plant passing through the side hole of the cage. The aphids’ development was checked every 24 h, from the first instars to the death of the adults (Fig. 1). A magnifier 55x was used to monitor the insects. Daily temperature
and humidity were measured with Digital hygrothermometer. The temperature ranged from 16–32°C, and the relative humidity was 27–95%. Each experiment was replicated 45 times for each condition.

Data analysis

Data were analyzed using age-stage, two-sex life table theory (Chi & Liu, 1985) and the method described by Chi (1988). To facilitate the tedious procedure, data analysis and population parameters were calculated using the TWOSEX-MSChart program designed in visual BASIC for the Windows operation system (Chi, 2015). The TWOSEX-MSChart is available at http://140.120.197.173/Ecology/prod02.htm (Chung sing University) and http://nhsbig.inhs.uiuc.edu/wes/chi.html (Illinois Natural History Survey).

The age-stage specific survival rate ($S_{xj}$) (where $x$= age and $j$= stage), the age-stage specific fecundity ($f_{xj}$), the age-specific survival rate ($l_x$), the age-specific fecundity ($m_x$), and the population parameters ($r$, the intrinsic rate of increase; $\lambda$, the finite rate of increase; $R_0$, the net reproductive rate, and $T$, the mean generation time) were calculated accordingly.

The means and standard errors of the life table parameters were estimated with the bootstrap ($n=10,000$) method (Efron & Tibshirani, 1993). Differences between treatments were then compared by using the paired bootstrap test (Efron and Tibshirani, 1993, Polat-Akköprü et al. 2015).

Fig. 1. Leaf cage used to study life table of Aphis craccivora under field condition.

Results

The developmental times for each stage are listed in Table 1. The first, second and fourth instar nymphs of A. craccivora showed significantly slower development under natural condition (Table 1). However, no significant differences were found in third instar nymph of A. craccivora reared in both natural and laboratory conditions. The adult longevity and total life span of A. craccivora was significantly shorter under natural condition.

The parameters $l_x$, $m_x$, and age-specific maternity ($l_xm_x$) are plotted in fig. 2. The survival rate ($l_x$) in the laboratory condition was higher. The trend of age-specific fecundity ($m_x$) showed that reproduction began at the age of 7 days in both laboratory and field. The highest fecundity occurred at the ages of 13 and 12 days in laboratory and natural conditions, respectively. Based on the age-stage, two-sex life table, the age-stage-specific life expectancy ($e_{xj}$) gives the expected life span of an individual of age $x$ and stage $j$ can live after age $x$ (fig. 3). The trends of life expectancy in both conditions were almost equal but life expectancy of A. craccivora in laboratory was higher. The age-stage specific survival rates ($s_{xj}$) showed the probability of a newborn surviving
to age $x$ and stage $j$. The age-stage specific survival rates of $A. \text{craccivora}$ under field and laboratory conditions are shown in fig. 4. The survival rate of $A. \text{craccivora}$ in laboratory condition was higher. The reproductive value ($v_{xj}$) is the contribution of individuals of age $x$ and stage $j$ to the future population (fig. 5). The results revealed that female with ages of 8 and 7 days made the highest contribution to the population when reared in laboratory and natural conditions, respectively.

Table 2 presents significant differences of population parameters of $A. \text{craccivora}$ between laboratory and natural conditions. The intrinsic rate of increase ($r$), the finite rate of increase ($\lambda$), net reproductive rate ($R_0$) and gross reproductive rate ($\text{GRR}$) were significantly higher under laboratory condition. Mean generation time ($T$) was significantly lower under laboratory condition.

Fig. 2. Age-specific survival rate ($l_x$), age-specific fecundity ($m_x$) and age-specific maternity ($l_xm_x$) of $Aphis \text{craccivora}$ under laboratory and field conditions.

Fig. 3. Age-stage specific life expectancy of $Aphis \text{craccivora}$ under laboratory and field conditions.
Table 1. Mean developmental times in days (mean ± SE), longevity and fecundity of *Aphis craccivora* in laboratory at 25 ± 1°C, 70% ± 5% RH, photoperiod 16:8h (L: D) and in natural condition (range of temperature 16°C -33°C and 32-89% of RH).

<table>
<thead>
<tr>
<th>Stages</th>
<th>Laboratory</th>
<th>Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>First instar nymph</td>
<td>2.02 ± 0.04b</td>
<td>2.18 ± 0.06a</td>
</tr>
<tr>
<td>Second instar nymph</td>
<td>1.89 ± 0.07b</td>
<td>2.36 ± 0.08a</td>
</tr>
<tr>
<td>Third instar nymph</td>
<td>1.98 ± 0.07a</td>
<td>2.09 ± 0.05a</td>
</tr>
<tr>
<td>Fourth instar nymph</td>
<td>1.98 ± 0.04b</td>
<td>2.13 ± 0.05a</td>
</tr>
<tr>
<td>Immature</td>
<td>7.87 ± 0.088b</td>
<td>8.76 ± 0.106a</td>
</tr>
<tr>
<td>Adult longevity</td>
<td>16.42 ± 0.374a</td>
<td>12.69 ± 0.807b</td>
</tr>
<tr>
<td>Life span</td>
<td>24.29 ± 0.376a</td>
<td>21.44 ± 0.784b</td>
</tr>
</tbody>
</table>

Mean in the same row followed by the same letter are not significantly different (Paired bootstrap test, P<0.05).

Table 2. Life table parameters (Means ± SE) of *Aphis craccivora* in laboratory at 25 ± 1°C, 70±5 % RH, photoperiod 16:8h (L: D) and in natural condition (temperature ranged 16°C - 33 C and 32-89% RH).

<table>
<thead>
<tr>
<th>Population parameters</th>
<th>Laboratory</th>
<th>Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic rate of increase (<em>r</em> (day⁻¹))</td>
<td>0.2339 ± 0.0037a</td>
<td>0.1906 ± 0.0055b</td>
</tr>
<tr>
<td>Finite rate of increase (<em>λ</em> (day⁻¹))</td>
<td>1.2635 ± 0.00462a</td>
<td>1.2100 ± 0.0066b</td>
</tr>
<tr>
<td>Net reproductive rate (<em>R₀</em> (offspring))</td>
<td>21.033 ± 0.71303a</td>
<td>13.689 ± 0.9573b</td>
</tr>
<tr>
<td>Mean generation time (<em>T</em> (day))</td>
<td>13.023 ± 0.148b</td>
<td>13.73 ± 0.228a</td>
</tr>
<tr>
<td>Gross reproductive rate (<em>GRR</em> (offspring))</td>
<td>23.439 ± 0.855a</td>
<td>18.164 ± 0.893b</td>
</tr>
</tbody>
</table>

Means in the same row followed by the same letter are not significantly different (Paired bootstrap test, P<0.05).

Fig. 4. Age-stage specific survival rate of *Aphis craccivora* under laboratory and field conditions.
Discussion

Our study showed that immature development times of *A. craccivora* under field conditions were higher, except for the third instar nymphs with no significant difference. The prolonged immature developmental times in the field may reflect the unsuitability of the environmental conditions. Our result were consistent with those of Zanuncio et al. (2006) who stated that longevity of the predatory pentatomid, *Brontocoris tabidus* (Signoret), was longer under field conditions. Afshari et al. (2007) mentioned that the fluctuating climatic and natural conditions of cotton fields could increase immature development time and decrease adult development times and reproduction of *A. gossypii*. Similar results were found for nymphal developmental stage of *Bactericera cockerelli* (Sulc) on tomato (Yang et al., 2013) and *Aphis gossypii* Glover on *Hibiscus syriacus* L. (Hosseini-Tabesh et al., 2015) except for the fifth and first instar nymphs, respectively.

The adult longevity and life span of *A. gossypii* in field conditions were found to be shorter due to the fluctuating temperature and humidity of field conditions. Yang et al. (2013) reported that female longevity of *B. cockerelli* reared on tomato were shorter under field conditions (16.2±0.9 days) comparing to laboratory conditions (60.5±8.4 days). According to Hosseini-Tabesh et al. (2015), shorter adult longevity of *A. gossypii* occurred in field, which is consistent with our finding. These results corroborate studies on reverse relationship between temperature and adult longevity of *Hyalopterus pruni* (Geoffroy) (Latham & Mills, 2011), mean developmental times of *Bemisia argentifolii* (Bellows & Perring) (Yang & Chi, 2006), *Brachycudus schwartzii* (Börner) (Satar & Yokomi, 2002) and *Aphis spiraecola* Patch (Wang & Tsai, 2000). Zamani et al. (2006) also reported that temperature had negative impact on the developmental time of *A. gossypii* reared on *Cucumis sativus* L. under laboratory conditions.

In the past, the response of aphids to environmental conditions has been used to develop phenological models to forecast aphid outbreaks (Collier et al., 1994; Ro et al., 1998). Dixon (1987) showed that the length of time required for an aphid from birth to adult is variable and dependent on two intrinsic factors, birth weight, whether the morph is winged or unwinged, and two extrinsic factors, food quality and weather conditions (especially temperature). Environmental conditions, such as temperature and relative humidity determine the physiological state of insects that are the key variables regulating their survival, fecundity, and population growth. Different temperature and relative humidity were important factors in significant differences (25 ± 1°C, 70±5% RH and 16–32°C, and 27–95% RH, respectively). Similar studies found that aphid population dynamics was affected by the abiotic factors such as environmental factors (Rugile & Gutierrez, 1995; Diaz & Fereres, 2005; Arbab et al., 2006; Hosseini-Tabesh et al., 2015).

In this study, the life table parameters of *A. gossypii* showed significant differences between field and laboratory conditions. Since intrinsic rate of increase (*r*) is the reflection of several factors such as fecundity, survival and generation time and physiological qualities
of an animal in relation to its capacity to increase, it would be an appropriate index to evaluate the performance of an insect in different situations (Kocourek et al., 1994; Southwood & Henderson, 2000). The $r$ value is more useful to compare the population growth potential of different species than $R_0$ (Price, 1997). The Intrinsic rate of increase ($r$) was 0.2339 and 0.1906 $d^{-1}$ under laboratory and natural conditions, respectively. According to Obopile & Oshitile (2010), the $r$ value of A. craccivora on five cowpea Vigna unguiculata (L.) varieties under laboratory condition ranged from 0.32±0.01 to 0.36±0.01 $d^{-1}$, that was higher than our results (0.1906 ±0.0055 and 0.2339 ±0.0037 $d^{-1}$ in natural and laboratory conditions, respectively). These differences may be due to discrepancy in host plants and environmental conditions such as temperature and relative humidity. The $r$ of B. cockerelli fed on potato was also significantly higher in the laboratory (0.1966 $d^{-1}$) than in field conditions (0.1015 $d^{-1}$) (Yang et al., 2010). Hosseini-Tabesh et al. (2015) reported higher intrinsic rate of increase of A. gossypii in laboratory condition. The higher $r$ value in laboratory condition indicated that A. craccivora had a greater reproductive potential and more suitability. The $R_0$ was also significantly higher under laboratory conditions. Similar results was found for melon flies (Huang & Chi, 2013) and A. gossypii (Hosseini-Tabesh et al., 2015), as the net reproductive rate was calculated higher under laboratory conditions. The mean generation time ($T$) for A. craccivora in laboratory condition was significantly higher, suggesting that laboratory condition is more suitable for A. craccivora.

It is concluded that life table of insect pests in field conditions could be a useful tool for making accurate management decisions and selecting proper measures to control insect pests of economically important crops. The differences reported here between the laboratory and field studies, together with the life table analysis, provide valuable information leading to establish a successful control program.

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References


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