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Effect of temperature on the demographic parameters of Asiatic apple leafminer, *Phyllonorycter ringoniella* Matsumura (Lepidoptera: Gracillariidae)

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ABSTRACT

Asiatic apple leafminer, *Phyllonorycter ringoniella* Matsumura (Lepidoptera: Gracillariidae) is an important insect pest of apple. The effect of five constant temperatures (13.3, 15.3, 20.7, 26.1, and 30.0 °C) on the demography of *P. ringoniella* was examined and the data were analyzed by life table parameters using jackknife technique. Developmental period of immatures (25.9–76.4 d) showed significant negative relationship to the temperatures with high temperature inhibition at 30 °C. Immature survival was highest at 20.7 °C and lowest at 30.0 °C. Temperature did not affect the 1:1 female:male ratio. Adult females lived longer (18.6 d) and produced highest number of eggs (94.0/female) at 15.3 °C but lived shorter (5.4 d) and produced least eggs (13.6/female) at 30.0 °C. Population growth parameters of net reproductive rate (R_0), intrinsic rate of increase (r), and finite rate of increase (λ) were higher at 20.7 °C. Mean generation time (T) decreased from 85.2 to 30.5 d as temperature increased from 13.3 to 30 °C, while the population doubling time (DT) was shortest (10.7 d) at 20.7 °C. This is the first detailed report on the demographic biology of *P. ringoniella*, and could facilitate the understanding of population dynamics and could help in decision making for *P. ringoniella* management in apple orchards.

Introduction

Asiatic apple leafminer, *Phyllonorycter* (*Lithocolletis*) *ringoniella* Matsumura (Lepidoptera: Gracillariidae), is an important insect pest on apple trees with four to six generations a year in Korea, Japan, and China (Lee et al., 1985a; Sugie et al., 1986; Sun et al., 2000; Sun et al., 2007; Kumar et al., 2014). The host ranges of *P. ringoniella* are relatively narrow to some pome and stone fruits such as apple, pear, peach, cherry, and plum (Du et al., 2013). The larvae develop in a mine made on the underside of the leaf and pupate inside it. In early infestation, silvery-green spots of irregular shape on the lower surface of the leaf and greenish-white appearance on the upper surface of the leaf can be noticed (Sekita and Yamada, 1979). The mines caused by *P. ringoniella* can reduce the photosynthetic area, hasten defoliation, and inhibit the growth of new buds, which may finally cause premature ripening and fruit drop (Lee et al., 1985b; Sugie et al., 1986; Shi et al., 2009). Since the 1990s, *P. ringoniella* had been widely expanded into the major apple-growing regions in China, and has the outbreak potential resulting > 80% leaf damage in some outbreak years (Shi et al., 2009; Du et al., 2013).

Life table analysis is useful to assess climatic adaptation and population growth potential with temperature-dependent development and adult performance study. Demographic parameters from the life table could indicate population growth capacity and bioclimatic adaptation to the new environment (Southwood and Henderson, 2000). Also it could be adapted to population models and help understanding interactions with other insect pests and natural enemies (Carey, 1982). Life table analysis is a standard ecological method to estimate the demographic parameters, and this information can be applied for examining the dynamics of colonizing or invading species or extinction probability, or predicting pest outbreak or life history evolution (Granett et al., 1983; Trichilo and Leigh, 1985; Carey et al., 1988; Omer et al., 1992; Vargas et al., 2000; Papadopoulos et al., 2002; Amiri et al., 2010; Carey et al., 2012; Ravuiwasa et al., 2012; Damos, 2013). Most influential environmental variables affecting *P. ringoniella* was reported as temperature; a few studies had dealt with the partial biology of *P. ringoniella* on temperature-dependent development, seasonal occurrences, and its mass flight activity (Lee et al., 1985a, 1985b; Sugie et al., 1986; Sekita, 2000; Sun et al., 2000; Sun et al., 2007; Li et al., 2017). However, the information on demographic parameters of *P. ringoniella* is lacking.

The comprehensive knowledge of the demographic characteristics of *P. ringoniella* under various temperatures would greatly facilitate the understanding of population dynamics and could help in decision making process of *P. ringoniella* management in apple orchards. This study was to determine the various demographic parameters of *P.*

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ringoniella under different constant temperatures.

Materials and methods

Insect rearing

A colony of *P. ringoniella* was established in the laboratory of Insect Ecology at Andong National University, which had been originally collected from one apple orchard in Hogye, Mungyeong, Gyeongbuk, South Korea (36°41′N, 128°13′E), in February 2016. The colony was maintained in growth chamber with temperature at 25 ± 1 °C, 65 ± 5% RH, and a photoperiod of 14:10 (L:D) h. Field collected overwintering pupae were separately placed in a small Petri dishes (5.5 cm diameter, 1.5 cm height) and then kept in the growth chamber. After emergence, 10–20 pairs of adults were transferred into plastic cubic rearing cage (40 × 40 × 40 cm, side ventilation) and supplied with 10% sugar solution. The cotton ball moistened with 10% sugar solution was changed every other day. The crabapple *Malus prunifolia* (Rosales: Rosaceae) seedlings were grown in single pots (10 cm diameter, 10 cm height) filled with the commercial soil (Plant world, Korea). The three-month old crabapple seedlings (nearly 20 cm height) were exposed to mating cage for 12 h. The exposed seedlings were kept in the growth chamber until the *P. ringoniella* in the leaves developed into pupae stage. The newly developed pupae (< 24 h) within the leaf mines were separately placed in the small Petri dishes (5.5 cm diameter, 1.5 cm height) for adult emergence and then reproducing next generations. A piece of cotton moistened with distilled water was placed into each Petri dish to maintain humidity.

Temperature effect on immature development

The developments and survivals of eggs, larvae, and pupae were examined in growth chambers with five designated constant temperatures (13, 15, 20, 25, and 30 °C). All experiments were conducted under a photoperiod of 14:10 (L:D) h. Temperature and humidity in each chamber were recorded hourly using one integrated data logger (EL-USB-2, Lascar Electronics Ltd., Salisbury, United Kingdom) during the experimental periods. Humidity ranged 60–80% independent to the set temperature, but the actual temperatures were different to the assigned temperatures; 13.3 ± 0.92, 15.3 ± 0.49, 20.7 ± 0.29, 26.1 ± 0.47, and 30.0 ± 0.68 (mean ± SD) °C, in each assigned temperatures growth chambers, respectively. The actual temperatures were used for further data analysis.

Eggs were deposited on the potted crabapple seedlings (≈ 20 cm height, with 5 mature leaves) by 12 h exposure to the rearing cage. Totally 120–200 eggs that were deposited singly in 9–17 seedlings were examined at each temperature. The egg developments were tracked and checked daily using a binocular stereomicroscope (Olympus SZ51, Olympus Corporation). After eggs hatched in each temperature, the larval development was daily monitored. Once pupation occurred in each temperature, pupae were separated from the leaf and placed individually into Petri dishes (5.5 cm diameter, 1.5 cm height) with a piece of cotton moistened with distilled water to maintain humidity. The pupal developments were observed daily until adult emergence or death. The survival rates of eggs, larvae, and pupae were calculated after all cohort individuals got into the adult stages.

Temperature effect on adult performance

Once adults emerged from pupae in each cohort, their sexes were determined. The newly emerged adults were coupled (one female and one male) separately into the oviposition cages (plastic transparent cuboid cage, 6.5 × 6.5 × 9.5 cm) for copulating and oviposition. The oviposition cages were placed back to the same growth chambers where the immatures developed. The oviposition cage was ventilated with fabric mesh (4 cm diameter) at top surface and two opposite sides. The cage based on the cover, which was glued with a small plastic tube (1.5 cm diameter, 6.0 cm height, 5 ml volume) in its center. The cover could be removed and reinstalled from the cage for experimental process. One leaf pruned with stem from the potted crabapple seedlings, was inserted into the tube (filled with tap water) in the center of the cover as an oviposition substrate. A piece of cotton moistened with 10% sugar solution was placed in each cage cover as food for the adults. The number of adults survived (longevity) and the number of eggs laid (include which on leaf and the sides of cage) were recorded daily. The leaves and 10% sugar solution were changed daily.

Life table analysis

The reproductive and demographic parameters were estimated following the methods described in previous studies (Birch, 1948; Carey, 1982; Amiri et al., 2010) after the construction of the respective life tables for each cohort at the five constant temperature regimes.

The reproductive parameters were estimated by the following equations:

Adult life expectancy (e_x, days):

$$e_x = \sum_{y=x}^{\infty} \frac{l_y}{l_x}$$

Gross fecundity rate (*GF*, eggs):

$$GF = \sum_{x=a}^{b} M_x$$

Net fecundity rate (*NF*, eggs):

$$NF = \sum_{x=a}^{b} l_x M_x$$

Gross fertility rate (*Gf*, eggs):

$$Gf = \sum_{x=a}^{b} M_x h_x$$

Net fertility rate (*Nf*, eggs):

$$Nf = \sum_{x=a}^{b} l_x M_x h_x$$

Daily eggs production (*De*, eggs/female/day):

$$De = \sum_{x=a}^{b} M_x \Big/ e_0$$

Daily fertile eggs production (*Dfe*, fertile eggs/female/day):

$$Dfe = \sum_{x=a}^{b} m_x h_x \Big/ e_0$$

where x is female adult age in days and beginning with “0”, a age at start of reproduction, b age at end of reproduction, l_x proportion of female adults surviving to age x, M_x number of eggs laid per female at age x, m_x number of female offspring per female at age x (age-specific fecundity), h_x proportion of eggs hatch for those eggs laid at age x.

The demographic parameters were estimated by the following equations:

Net reproductive rate (R_0):

$$R_0 = \sum_{x=a}^{b} l_x m_x$$

Intrinsic rate of increase (r):

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

Finite rate of increase (λ):