



Effects of Temperature on Life History Traits of *Ophraella communa* (Coleoptera: Chrysomelidae) on *Parthenium hysterophorus* (Asteraceae)

Wen-Hua Chen^{1*}, Vahid Naoaitoro^{1*}, Lekhnath Kafle², Min-Nan Tseng³, and Tsui-Ying Chang^{1**}

¹ Department of Plant Medicine, National Pingtung University of Science and Technology, Pingtung, Taiwan

² Department of Tropical Agriculture and International Cooperation, National Pingtung University of Science and Technology, Pingtung, Taiwan

³ Kaohsiung District Agricultural Research and Extension Station, Pingtung, Taiwan

* Authors with equal contributions

**Corresponding email: tychang@mail.npust.edu.tw

Received: 5 May 2019 Accepted: 3 July 2019 Available online: 9 August 2019

ABSTRACT

Bitterweed (*Parthenium hysterophorus*) is a weed of economic concern in locations of invasion and is native to Central and South America. The ragweed leaf beetle (RLB, *Ophraella communa*) has been reported as a potential biocontrol agent. This study investigated the life history of RLBs on bitterweed under laboratory conditions at three different temperatures (20, 25, and 30°C). The objectives of this study were to identify the favorable temperature for RLBs to develop on bitterweed and to determine effects of temperature on both sexes of the immature stages and adults. The study results revealed that the developmental period decreased with an increase in temperature and that the period exhibited no statistical difference between the sexes at the same temperature. Survival rate per stage was highest at 25°C and lowest at 20°C and decreased with an increase in age. Fecundity was highest at 25°C and lowest at 20°C on bitterweed. These results thus demonstrate that 25°C had the most favorable effects on the life history of the RLBs on bitterweed.

Key words: bitterweed, ragweed leaf beetle, immature stages, different sexes, temperature

Introduction

Bitterweed (*Parthenium hysterophorus* L.) is an invasive species native to South and Central America. The invasive weed has since spread to Asia, Africa, Australia, and other regions of the world, causing damage to both

agricultural and urban lands it invades (Rollins, 1950; Evans, 1997). In invaded lands, bitterweed was also documented to have caused health problems, especially allergy in individuals with asthma. To address the problems associated with the invasive weed species, various studies have been conducted globally in affected areas to

determine how to control the *Parthenium* weed effectively. Different countries invaded by bitterweed apply various control methods, including the execution of weeding and plowing, use of chemical herbicides such as glyphosate-phenoxy, and use of biological control agents.

Due to the negative effects of synthetic herbicides on the environment and human health, alternatives have been explored, such as the use of beneficial insects as biological control agents. In South American regions (which are native to bitterweed), certain insects have been tested as effective biocontrol agents against bitterweed; such insects have also been tested in other countries invaded by bitterweed. Among the tested biological control agents against bitterweed, *Zygogramma bicolorata* Pallister, *Zygogramma suturalis*, *Epiblema strenuana*, *Liothrips* sp., *Euaresta bella* L., and *Tarachidia candefacta* (Hubner) have been reported as effective (Ma *et al.*, 2008; Zhou *et al.*, 2017). Other insects that feed on bitterweed are *Anopheles gambiae*, *Tarachida erastrioides* Hbn, *Z. suturalis* F., *Systema blanda*, and stem-galling moths. Similarly, rodents (*Microtus pennsylvanicus*, *Peromyscus leucopus*) and snails feed on bitterweed (MacDonald and Kotanen, 2010; Zhou *et al.*, 2017).

The ragweed leaf beetle (RLB), a potential biocontrol agent against bitterweed, is native to North America (Futuyma, 1990; Palmer and Goeden, 1991). Wang and Chiang (1998), Zhou *et al.* (2010), and Zhou *et al.* (2014) have reported that the first recorded appearance of the RLB was 1996 in Japan, 2001 in China, 2000 in Korea, and 1996 in Taiwan, respectively. In Europe, the first recorded appearance of the RLB was made in Switzerland and Italy in 2013; the RLB was later observed in France, Germany, Hungary, and Russia (Schaffner *et al.*, 2014).

Originally, the RLB fed on only one host species, *A. artemisiifolia* (Bosio *et al.*, 2014). However, the RLB currently feeds on other members of the subtribes Ambrosiinae, including the ragweed *Xanthium strumarium* L. and *Ambrosia psilostachya* DC as well as the sunflower *Helianthus annuus* L. (Palmer and Goeden, 1991; Dernovici *et al.*, 2006).

Watson and Teshler (2013) reported that the effectiveness of the RLB in inducing defoliation is low due to strong attack by predators and

parasitoids on the RLB. In Europe and East Asia, the RLB has shown great potential as a biological control agent by causing 100% or total defoliation of *A. artemisiifolia* (Gerber *et al.*, 2011; Bosio *et al.*, 2014; Schaffner *et al.*, 2014).

Sunflower is one of the fundamental host plants for the RLB. Dernovici *et al.* (2006) investigated the risk of RLB-induced sunflower damage and concluded that the damage caused was negligible due to a lack of egg production and because the survival rate of first instar larvae was less than 50% on the sunflower. They also reported that RLBs could on sunflower, but succeeding generations could not survive by feeding on sunflower.

Zhou *et al.* (2011) conducted a field experiment by assessing the survival and population density of RLBs on six varieties of sunflower when intercropped with the common ragweed. The results showed that all RLB stages failed to establish themselves on the different sunflower varieties when intercropped with the common ragweed over a period of two months (from July to August). Watson and Teshler (2013) performed a similar comparative study on the risk of RLB-induced sunflower and common ragweed damage. They placed 70 females (10 females/cultivar) on 7 sunflower cultivars and 10 females on common ragweed. Their experimental results showed that the RLB has great potential to cause damage to sunflowers. However, the mortality rate of first instar larvae was 50% and that of adult females exceeded 50% on the 30th day of sampling, whereas the mortality rate of the female RLBs on common ragweed exceeded 50% after 60 days.

Studies have shown the RLB to be a potential control agent against bitterweed (Palmer and Goeden, 1991; McClay *et al.*, 1995; Dernovici *et al.*, 2006). To determine whether the RLB is a biological control agent against ragweed, the life history of the insect was studied in the current study at three different temperatures (20, 25, and 30°C). According to Nylin (2001), life history traits would typically include reproduction and development, such as number of offspring; offspring mass, age, and mass at first reproduction; and number of reproductive events and the intervals between them. Hence, to determine the life history of the RLB on bitterweed, different parameters,

including the developmental period, body measurement, survival rate, preoviposition, oviposition, postoviposition, longevity of adults, and fecundity, were studied.

Materials and Methods

RLBs (*Ophraella communa*)

Parthenium plants with attached RLB adults and larvae were collected from Pingtung County and returned to the laboratory. The collected RLBs were then transferred to the greenhouse of the Department of Plant Medicine at National Pingtung University of Science and Technology, where they were cultured for the experiment.

The collected RLBs were reared in two insect-rearing cages (length \times width \times height: 2.3 m \times 1.2 m \times 0.8 m) in the greenhouse under natural light and dark conditions. The room temperature and relative humidity observed in the greenhouse were $25 \pm 5^\circ\text{C}$ and $65 \pm 10\%$, respectively.

Pupae were collected from the RLB population in the greenhouse and then brought to the laboratory for rearing. In the laboratory, hand towel tissues were placed in a container (length \times width \times height: 25 cm \times 20 cm \times 16 cm); cotton wool was moistened and then placed in a 6-cm Petri dish, which was subsequently inserted in the container (length \times width \times height: 25 cm \times 20 cm \times 16 cm). Two bitterweed leaves were then inserted into 5-mL water-holding tubes and placed on the hand tissues. The pupa-rearing container contained six water-holding tubes. The pupae were reared in this container until adult emergence.

Bitterweed (*P. hysterophorus*)

Young *Parthenium* plants were collected from areas outside National Pingtung University of Science and Technology. The collected

Parthenium plants were planted using 30% peat moss and 70% soil and watered twice daily.

Pairing of *O. communa*

After adults emerged, adult male and female RLBs were randomly picked from the pupa-rearing container for mating. The adult male and female insects were paired and placed in 9-cm Petri dishes (one pair per Petri dish) on the second day after emergence. Their twigs were then attached with moistened cotton wool and placed in the Petri dishes, with each Petri dish containing one leaf (Xion, 1992). The paired RLB adults were then transferred onto the leaf in the Petri dish, which was then sealed with transparent plastic wrapper. The transparent plastic wrapper covering each Petri dish was then pierced with needles, creating 10 pores per Petri dish (9 cm). Those Petri dishes containing paired adults were then placed on trays under room temperature ($25 \pm 5^\circ\text{C}$) for mating. The number of adult male and female pairs and other details are presented in Table 1.

Collection of eggs for life history study

Among the paired RLB adults, 20 eggs from the first oviposition were collected from each pair and reared in a Petri dish (3.5 cm; Taylor *et al.*, 2015). Eggs collected from different pairs were reared separately (20 eggs per Petri dish). Because more than 20 eggs were collected from the same pairs, some eggs were randomly excluded from each treatment (Iranipour *et al.*, 2016). To rear the eggs, cotton wool was moistened and placed in the Petri dish (3.5 cm; Ju *et al.*, 2011). The eggs were then placed into growth chambers with respective temperatures of 20, 25, and 30°C , a relative humidity of $75 \pm 5\%$, and photoperiod of 14 hours of light and 10 hours of darkness. The eggs were reared until hatching. The egg incubation period of each test temperature was observed (Table 1).

Table 1. Total initial sample size of RLBs on bitterweed, serving as a host plant, at different temperatures

| Temperature ($^\circ\text{C}$) | No. of adult pairs | No. of eggs/pair | Total no. eggs |
|----------------------------------|--------------------|------------------|----------------|
| 20 | 8 | 20 | 160 |
| 25 | 6 | 20 | 120 |
| 30 | 7 | 20 | 140 |

Transferring of larvae and rearing

One-day-old larvae were then transferred into Petri dishes (3.5 cm), with one larva per Petri dish serving as one replication (Yadav and Chang, 2014). In each Petri dish, a piece of leaf measuring approximately 2.5 cm was prepared and placed on moistened cotton wool. The Petri dishes were then covered with transparent plastic wrapper, through which five pores were pierced. Each Petri dish was then labeled with the larval number, date of transfer into the Petri dish or hatching, and the temperature condition under which each larva would be reared. The bitterweed leaf in each Petri dish was replaced every three days for the first and second larval instar stages and every two days for the third instar stage. All larvae and the pupal stage were reared individually in the same Petri dish, and the immature developmental time of each stage was recorded until adult emergence.

Pairing of adults

Newly emerged RLB adults were sexed and paired into 9-cm Petri dishes on the second day after emergence for mating and egg production. The preparation of the Petri dishes was the same as in Table 1. The leaf in each Petri dish was replaced daily.

Data collection

This study first collected data regarding the developmental periods of the immature stages: from eggs to adult emergence. For eggs, data regarding the developmental period were collected from the first day of production to the day of hatching. For all developmental stages, data were collected according to the procedure described by Zhou *et al.* (2010), Zhu *et al.* (2012), and Iranipour *et al.* (2016), with modifications. Specifically, in this study, data were collected from the first day of hatching for eggs, from the first day after molting to the day of molting into next stage for the larval stages, and from the first day of cocoon formation until the day of adult emergence for the pupal stage. The effects of temperature on egg hatchability and the total survival rate of each developmental stage of the RLBs on ragweed were investigated.

Data regarding daily egg production were collected daily. Each old leaf with attached eggs was replaced with a fresh leaf. The leaf with

attached eggs was then placed under a microscope (ZEISS Stemi DV4, Ziess Discovery, Wetzlar, Germany) to count the numbers of eggs. The eggs were counted using a desk tally counter (H-102E, Cosmos Precision Works, Japan). Total numbers of eggs per female were recorded while the female was alive and laying eggs.

Sex was determined in the RLBs through observations of body size and abdomen (size and color). The body lengths of males and females were differentiated according to the methods described by Zhou *et al.* (2012) and Chen *et al.* (2014). When there was a shortage of males, adult males were collected from the RLB population in the greenhouse to pair up with the available female(s); moreover, whenever there was a shortage of females, newly emerged female(s) would be kept (Zhou *et al.*, 2010; Chen *et al.*, 2016).

For comparisons of the developmental period, survival rates, longevity, and fecundity of the RLBs at different temperatures, means and standard errors were determined using SPSS software version 25 (IBM SPSS statistics V25, 2017). Significant differences ($P < 0.05$) between means were compared through Tukey's test.

Results

Developmental period of RLBs

Temperature had a relatively high effect on the developmental periods of RLBs that fed on bitterweed. The results showed that for both sexes, the developmental periods of the same immature stage differed significantly at the three different temperatures (egg: $F = 879.425$, $P = 0.001$, $DF = 223$; first instar larvae: $F = 481.199$, $P = 0.001$, $DF = 223$; second instar larvae: $F = 818.842$, $P = 0.001$, $DF = 223$; third instar larvae: $F = 501.315$, $P = 0.001$, $DF = 223$; Pupa: $F = 451.008$, $P = 0.001$, $DF = 223$). However, the developmental periods of males and females at the same temperature were not significantly different (Table 2).

The developmental period of the RLBs was longest at 20°C and shortest at 30°C for all immature stages. Similarly, for the immature stages, the developmental periods of both male and female RLB adults on ragweed were highest at 20°C and lowest at 30°C (Table 2).

Table 2. Developmental period (days, mean ± SE) of RLBs on bitterweed at three different temperatures

| Temp. (°C) | Sex | n | Development period (days, mean ± SE)* | | | | | |
|---------------|-----|----|---------------------------------------|------------------------|------------------------|------------------------|---------------|---------------|
| | | | Egg | 1 st Instar | 2 nd Instar | 3 rd Instar | Pupa | Egg-Adult |
| 20 | ♂ | 35 | 12.39 ± 0.16c | 11.5 ± 0.16c | 9.19 ± 0.17c | 7.11 ± 0.14c | 11.11 ± 0.17c | 51.36 ± 0.36c |
| | ♀ | 36 | 12.54 ± 0.02c | 11.6 ± 0.17c | 9.09 ± 0.16c | 7.20 ± 0.10c | 11.31 ± 0.17c | 51.71 ± 0.33c |
| 25 | ♂ | 41 | 6.48 ± 0.08b | 6.10 ± 0.14b | 2.97 ± 0.07bc | 2.89 ± 0.08b | 6.33 ± 0.12b | 25.25 ± 0.03b |
| | ♀ | 40 | 6.83 ± 0.06b | 6.20 ± 0.16b | 3.13 ± 0.08b | 3.05 ± 0.08b | 6.78 ± 0.02b | 25.97 ± 0.19b |
| 30 | ♂ | 39 | 5.47 ± 0.09a | 4.40 ± 0.12a | 2.53 ± 0.09a | 2.41 ± 0.08a | 5.56 ± 0.09a | 20.61 ± 0.27a |
| | ♀ | 38 | 5.82 ± 0.10a | 4.71 ± 0.12a | 2.63 ± 0.08a | 2.42 ± 0.08a | 5.71 ± 0.08a | 21.29 ± 0.18a |

*Means within the same column followed by different letters are significantly different at the 5% significance level according to Tukey's tests.

Table 3. Survival of immature and adult RLBs on bitterweed at three different temperatures

| Temp. (°C) | N | Survival rate (%) | | | | | |
|---------------|-----|-------------------|------------------------|------------------------|------------------------|----------------|---------------|
| | | Egg | 1 st Instar | 2 nd Instar | 3 rd Instar | Pupa | Egg-Adult |
| 20 | 160 | 49.5 ± 8.57a | 64.7 ± 11.09a | 65.59 ± 11.23a | 70.32 ± 12.32a | 76.53 ± 12.97a | 30.5 ± 4.91a |
| 25 | 120 | 92.5 ± 4.78b | 84.03 ± 3.59b | 86.00 ± 4.38a | 94.78 ± 1.79b | 98.74 ± 1.02b | 63.33 ± 6.67b |
| 30 | 140 | 57.5 ± 7.19a | 73.21 ± 8.91ab | 74.65 ± 8.73a | 94.19 ± 9.54b | 86.67 ± 9.91b | 37.50 ± 5.44a |

Means within the same column followed by different letters are significantly different at $P < 0.05$ according to analysis of variance (ANOVA): least significant difference test.

Survival rate of RLBs

Temperature had relatively high effects on egg hatchability and the total survival rate of each developmental stage of the RLBs on ragweed. The egg survival rate was highest at 25°C and lowest at 20°C ($F = 7.05, P = 0.004, DF = 25$). The same trends were observed for the first and third instar larval and pupal stages. However, the survival rate of the second instar larvae was not significantly different among the tested temperatures (first instar: $F = 0.91, P = 0.042, DF = 25$; second instar: $F = 1.01, P = 0.055, DF = 25$; third instar: $F = 1.25, P = 0.038, DF = 25$; Pupa: $F = 0.896, P = 0.042, DF = 25$). For the immature stage, the survival rate increased with temperature. For the total immature stages from egg to adult emergence, the survival rate was highest at 25°C and lowest at 30°C ($F = 7.86, DF = 0.003, DF = 25$; Table 3).

Preoviposition, oviposition, postposition, and adult longevity periods of RLBs on bitterweed

The experimental results showed that temperature had relatively high effects on the female preoviposition, oviposition, and postoviposition periods of the RLBs on bitterweed. Specifically, the results demonstrated that the preoviposition, oviposition, and postoviposition periods decreased with an increase in temperature (preoviposition: $F = 112.485, P = 0.001, DF = 116$; oviposition: $F = 52.351, P = 0.001, DF = 116$; postoviposition: $F = 112.226, P = 0.001, DF = 116$), as presented in Table 4.

The results showed that longevity for both males and females decreased with increasing temperature. For both adult sexes, RLB longevity was highest at 20°C and lowest at 30°C. For both sexes, the longevity of the same immature stage differed considerably at the different temperatures. However, the longevity periods of males at 25°C, both males and females at 30°C, and males at 25 and 30°C did not differ significantly. The longevity of males and females at the same temperature did not differ

Table 4. Preoviposition, oviposition, postposition, and adult longevity periods (days, mean \pm SE) of RLBs on bitterweed at three different temperatures

| Temperature ($^{\circ}$ C) | Sex | N | (days, mean \pm SE) | | | |
|--------------------------------|-----|----|-----------------------|--------------------|------------------|--------------------|
| | | | Pre-oviposition | Oviposition | Post-oviposition | Adult longevity |
| 20 | ♂ | 35 | - | - | - | 82.54 \pm 0.67c |
| | ♀ | 36 | 8.31 \pm 0.25 c | 64.53 \pm 0.73c | 5.14 \pm 0.28c | 77.97 \pm 0.53c |
| 25 | ♂ | 41 | - | - | - | 57.78 \pm 1.81ab |
| | ♀ | 40 | 4.90 \pm 0.19 b | 47.87 \pm 11.33b | 2.40 \pm 0.12b | 55.17 \pm 1.68a |
| 30 | ♂ | 39 | - | - | - | 39.11 \pm 2.36ab |
| | ♀ | 38 | 2.63 \pm 0.14 a | 33.39 \pm 1.56a | 0.84 \pm 0.13a | 38.95 \pm 1.00b |

Means within the same column followed by different letters are significantly different at $P < 0.05$ level according to ANOVA: Tukey's test.

Table 5. Fecundity of RLBs on bitterweed at three different temperatures

| Temperature ($^{\circ}$ C) | N | Total no. eggs/female | No. eggs/female/day |
|-----------------------------|----|-----------------------|---------------------|
| 20 | 36 | 458.75 \pm 21.19a | 6.06 \pm 0.16a |
| 25 | 40 | 1434.35 \pm 65.52c | 28.07 \pm 0.65c |
| 30 | 38 | 718.00 \pm 14.53b | 23.89 \pm 0.48b |

Means within the same column followed by different letters are statistically different at $P < 0.05$ according to ANOVA: Tukey's test.

significantly ($F = 271.447$, $P = 0.001$, $DF = 116$; Table 4).

Fecundity of RLBs

The results indicated that the total numbers of eggs laid per female at 20, 25, and 30 $^{\circ}$ C were significantly different. On ragweed, the total number of eggs laid per female was highest at 25 $^{\circ}$ C and lowest at 20 $^{\circ}$ C ($F = 127.115$, $P = 0.001$, $DF = 109$). The number of eggs laid per female per day was highest at 25 $^{\circ}$ C and lowest at 20 $^{\circ}$ C ($F = 517.353$, $P = 0.001$, $DF = 109$; Table 5).

Discussion

Cui *et al.* (2018) reported that insects are heterothermic poikilotherms, signifying that they are highly sensitive to temperature changes. Such changes may affect processes such as insect growth, development, reproduction, distribution, and population dynamics (Li *et al.*, 2017). The growth and development of insects tend to accelerate with a temperature increase in the favorable temperature range but are adversely affected when the temperature exceeds this range (Chen *et al.*, 2014).

The results of this study reveal that for both sexes, the developmental periods of the same immature stage at different temperatures were considerably different. The developmental periods of immature stages for both male and female RLBs on ragweed were highest at 20 $^{\circ}$ C and lowest at 30 $^{\circ}$ C.

The explanation for these results can be found in the literatures. The growth and development of ectotherms depend strongly on ambient temperature (Aguila *et al.*, 2014). When insects are subjected to relatively low or extreme low temperatures, their development is delayed or interrupted, thus causing prolonged developmental periods (Hance *et al.*, 2007). Furthermore, Yadav and Chang (2014) stated that a relatively low temperature caused immature insect stages to undergo diapause, resulting in a prolonged developmental period. The developmental period of the immature stages (egg to pupa) of insects is inversely proportional to an increase in temperature (Honek *et al.*, 2003). This could thus explain why the egg survival rate was highest at 25 $^{\circ}$ C and lowest at 20 $^{\circ}$ C. For the immature stage, the observed survival rate increased with

temperature. For the total immature stages from egg to adult, the observed survival rate was higher at 25°C and lower at 30°C. From the larval stage to the total immature stage, the survival rate was highest at 25°C and lowest at 20°C.

In most ectotherm species, longevity increases with decreasing temperature (and vice versa; Reznik *et al.*, 2009; Zhou *et al.*, 2010). Insect longevity peaks at optimum temperatures and exhibits a nearly symmetrical decrease at both the lower and upper limits of temperature tolerance (Irwin and Lee, 2000; Zani *et al.*, 2005).

According to Khaliq *et al.* (2014), temperature also had a considerable influence on the preoviposition, oviposition, and postoviposition periods of insects. They reported that the preovipositional period decreased with an increase in temperature, whereas the oviposition and postoviposition periods increased as the temperature increased to a certain level and then decreased with the survival rate.

The experimental results obtained in the present study are similar to those reported by Zhou *et al.* (2010) regarding the preoviposition and oviposition periods of RLBs on common ragweed; however, they did not report results for the postoviposition period.

The experimental results obtained in this study are also similar to those observed by Honek *et al.* (2003) regarding the preoviposition and postoviposition periods for *Gastrophysa viridula* at 25°C. Accordingly, the experimental results support the assertion that temperature substantially affects the preoviposition, oviposition, and postoviposition periods in an inversely proportional trend (Zhou *et al.*, 2010).

Honek *et al.* (2003) also observed that temperature had a substantial effect on the longevity of both male and female RLBs. The longevity shortened with the increase in temperature for both male and female RLBs. The current study revealed that at the same temperature, the longevity of males and females did not differ substantially. Zhong *et al.* (2015) provided evidence similar to these results, showing that longevity did not differ considerably between opposite-sex individuals of the same species raised together. The longevity periods of adult females raised at 25 and 30°C

were also shorter than those of individuals raised at 20°C because the most of the energy was diverted to egg formation and development, leaving fewer resources available to the female for maintenance of body functions, thus reducing survival.

Smith *et al.* (1990) reported that the fecundity of invertebrates is mostly affected by size, population density, food, age, temperature, geographic location, egg or offspring size, male ejaculate size, number of previous mating events by males, and clutch interval.

Temperature might influence insect fecundity at two time points: the time required for egg maturation and the time required for strategic oviposition of the egg by the adult female (Berger *et al.*, 2008). A relatively low temperature reduces fecundity due to male sterility; male sterility decreases the movement of both male and female adults such that mating no longer occurs or sperm is incapacitated (Danks *et al.*, 1994). Furthermore, temperature influences insect fecundity by affecting pupal weight and adult body size, resulting in larger females being more fecund than smaller ones (Calvo and Molina, 2005).

The results on fecundity obtained in the present study differ from those reported by previous studies on RLBs. According to the results reported by Zhou *et al.* (2010), the fecundity rate observed per female RLB ranged from 1,323.2 to 2,712.3 in the temperature range of 22 to 30°C. However, Meng and Li (2006) reported a lower fecundity of 295.4 to 312.1 eggs per female in the temperature range of 24 to 30°C. The present study revealed an egg production rate of 458.75 to 1434.35 in the temperature range of 20 to 30°C, demonstrating that temperature has considerable effects on the fecundity of the RLB. However, the aforementioned variations of fecundity in the same temperature ranges indicate that the RLB does not perform consistently even in a favorable temperature range. Fecundity is lowest at low temperatures due to the failure of female adults to convert all resources obtained into eggs (Leimar, 1996; Tamaru *et al.*, 2002). At favorable temperatures, ectotherms are active and search for their required energy sources (Berger *et al.*, 2008).

Kobori and Hanboonsong (2017) reported

that temperature is one of the major environmental factors affecting the biology, physiological, behavioral characteristics, and population dynamics of ectothermic organisms such as insects. Temperature affects nearly all rates of biological processes, including biochemical kinetics and species generation time (Kingsolver and Huey, 2008). According to Khaliq *et al.* (2014), both high and low temperatures have considerable effects on insects; specifically, a relatively high temperature affects the life cycle stage, growth, and some internal metabolic activities of insects, whereas a relatively low temperature disturbs the physiological, mechanical, and behavioral traits of insects. However, Zhou *et al.* (2013) demonstrated that exposure of a previous generation to extreme low temperatures has some positive effects on the next generation; specifically, offspring can adopt the phenotype and biological and ecological behaviors of the mother and thus achieve faster development, higher fecundity, and the ability to tolerate cold temperatures. Overall, temperature influences the performance and fitness components of ectotherms, including fecundity (Calvo and Molina, 2005; Hance *et al.*, 2007; Kingsolver and Huey, 2008).

Insects are poikilothermic organisms; therefore, temperature is one of the main factors determining their physiological processes and a key factor determining their phenology (Régnière *et al.*, 2012; Régnière and Powell, 2013). Ectotherm physiology is strongly temperature dependent, and activities are sufficiently executed only within certain temperature ranges (Berger *et al.*, 2008).

In conclusion, the experimental results of this study demonstrate that 25°C had the most favorable effects on the life history of RLBs on bitterweed. The study suggests that 25°C is the favorable temperature to develop mass rearing facilities of RLBs. However, a detailed field study is recommended to confirm the laboratory results regarding the potential of the RLB as a biocontrol agent against bitterweed.

Acknowledgment

The authors thank the IPM Laboratory, Department of Plant Medicine, National

Pingtung University of Science and Technology, for providing a research venue and continuous support throughout the research period. Special gratitude is also extended to the Taiwan International Cooperation and Development Fund and National Pingtung University of Science and Technology for their financial support.

References

- Aguilar A, Josep A, Joane FM.** 2014. Breaking the temperature-size rule: Thermal effects on growth, development and fecundity of a crustacean from temporary waters. *J Therm Bio* 42: 15-24.
- Berger D, Walters R, Gotthard K.** 2008. What limits insect fecundity? Body size and temperature-dependent egg maturation and oviposition in a butterfly. *Funct Ecol* 22: 523-529.
- Bosio G, Massobrio V, Chersi C, Scavarda G, Clark S.** 2014. Spread of the ragweed leaf beetle, *Ophraella communa* LeSage, 1986 (Coleoptera Chrysomelidae), in Piedmont Region (northwestern Italy). *Bollettino Della Società Entomologica Italiana* 146: 17-30.
- Calvo D, Molina JM.** 2005. Fecundity-body size relationship and other reproductive aspects of *Streblote panda* (Lepidoptera: Lasiocampidae). *Ann Entomol Soc Am* 98: 191-196.
- Chen HS, Zheng XW, Luo M, Guo JY, Luo YH, Zhou ZS, Wan FH.** 2014. Effects of high temperature on body size and weight of *Ophraella communa*. *Biocontrol Sci Technol* 24: 882-890.
- Chen WH, Li CY, Chang TY.** 2016. Temperature-dependent development and life history of *Oligonychus litchii* (Acari: Tetranychidae), on wax apple. *J Asia-Pac Entomol* 19: 173-179.
- Cui J, Zhu SY, Bi R, Xu W, Gao Y, Shi SS.** 2018. Effect of temperature on the development, survival, and fecundity of *Heliothis virescens* (Lepidoptera: Noctuidae). *J Econ Entomol* 111: 1940-1946.
- Danks HV, Kukal O, Ring RA.** 1994. Insect cold-hardiness: Insights from the Arctic. *Arctic* 47: 391-404.
- Dernovici SA, Teshler MP, Watson AK.** 2006. Is

- sunflower (*Helianthus annuus*) at risk to damage from *Ophraella communa*, a natural enemy of common ragweed (*Ambrosia artemisiifolia*)? *Biocontrol Sci Technol* 16: 669-686.
- Evans HC.** 1997. *Parthenium hysterophorus*: a review of its weed status and the possibilities for biological control. *Biocon News and Inform* 18: 89-98.
- Futuyma DJ.** 1990. Observations on the taxonomy and natural history of *Ophraella* Wilcox (Coleoptera: Chrysomelidae), with a description of a new species. *J New York Entomol Soc* 98: 163-186.
- Gerber E, Schaffner U, Gassmann A, Hinz HZ, Seier M, Muller SH.** 2011. Prospects for biological control of *Ambrosia artemisiifolia* in Europe: learning from the past. *Weed Res* 10: 1365-3180.
- Hance T, Baaren JV, Vernon P, Boivin G.** 2007. Impact of extreme temperatures on parasitoids in a climate change perspective. *Ann Rev Entomol* 52: 107-126.
- Honek A, Jarosik V, Martinkova Z.** 2003. Effect of temperature on development and reproduction in *Gastrophysa viridula* (Coleoptera: Chrysomelidae). *Eur J Entomol* 100: 295-300.
- IBM Corp.** 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.
- Iranipour S, Esfand K, Kazemi MH.** 2016. Life history of the Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae), on four potato varieties in Iran. *Crop Prot* 5: 139-148.
- Irwin JT, Lee RE.** 2000. Mild winter temperatures reduce survival and potential fecundity of the goldenrod gall fly, *Eurosta solidaginis* (Diptera: Tephritidae). *J Insect Physiol* 46: 655-661.
- Ju RT, Wang F, Li B.** 2011. Effects of temperature on the development and population growth of the sycamore lace bug, *Corythucha ciliata*. *J Insect Sci* 11: 1-12.
- Khaliq A, Javed M, Sohail M, Sagheer M.** 2014. Environmental effects on insects and their population dynamics. *J Entomol Zool Stud* 2: 1-7.
- Kingsolver JG, Huey RB.** 2008. Size, temperature, and fitness: three rules. *Evol Ecol Res* 10: 251-268.
- Kobori Y, Hanboonsong Y.** 2017. Effect of temperature on the development and reproduction of the sugarcane white leaf insect vector, *Matsumuratettix hiroglyphicus* (Matsumura) (Hemiptera: Cicadellidae). *J Asia-Pac Entomol* 20: 281-284.
- Leimar O.** 1996. Life history plasticity: influence of photoperiod on growth and development in common blue butterfly. *Oikos* 76: 228-234.
- Li GP, Feng HQ, Huang B, Zhong J, Tian C H, Qiu F, Huang JR.** 2017. Effects of short-term heat stress on survival and fecundity of two plant bugs: *Apolygus lucorum* (Meyer-Dür) and *Adelphocoris suturalis* Jakovlev (Hemiptera: Miridae). *Acta Ecol Sin* 37: 3939-3945.
- Ma J, Guo JY, Wan FH, Hu XN.** 2008. Biological control of *Ambrosia artemisiifolia* and *A. trifida*. pp 157-185. In: Wan FH, Li BP, Guo JY (eds.) *Biological Invasions: Biological Control Theory and Practice*. Science Press, Beijing.
- MacDonald AAM, Kotanen PM.** 2010. The effects of disturbance and enemy exclusion on performance of an invasive species, common ragweed, in its native range. *Oecologia* 162: 977-986.
- McClay AS, Palmer WA, Bennett FD, Pullen KR.** 1995. Phytophagous arthropods associated with *Parthenium hysterophorus* (Asteraceae) in North America. *Environ Entomol* 24: 796-809.
- Meng L, Li B.** 2006. Mating and oviposition behaviors of exotic leaf beetle, *Ophraella communa*. *Chinese Bull Entomol* 43: 806-809.
- Nylin S.** 2001. Life history perspectives on pest insects: What's the use? *Austral Ecol* 26: 507-517.
- Palmer WA, Goeden RD.** 1991. The host range of *Ophraella communa* Lesage (Coleoptera: Chrysomelidae). *Coleopt Bull* 45: 115-120.
- Régnière J and Powell JA.** 2013. Animal life cycle models (Poikilotherms). pp. 295-315. In Schwarz MD (ed.) *Phenology: An Integrative Environmental Science*. Springer, Dordrecht.
- Régnière J, Powell J, Bentz B, Nealis V.** 2012. Effects of temperature on development, survival and reproduction of insects:

- Experimental design, data analysis and modelling. *J Insect Physiol* 58: 634-647.
- Reznik SY, Voinovich ND, Vaghina NP.** 2009. Effect of temperature on the reproduction and development of *Trichogramma buesi* (Hymenoptera: Trichogrammatidae). *Eur J Entomol* 106: 535-544.
- Rollins RC.** 1950. The Guayule Rubber Plant. Harvard University No. 172, Cambridge, Ma, USA. pp. 72.
- Schaffner U, Lommen S, Schärer HM.** 2014. The EU cost action smarter-a European-wide approach for a sustainable management of common ragweed, *A. artemisiifolia*. *Atti Accademia Nazionale Italiana di Entomologia Anno LXII*, pp. 97-100.
- Smith GT.** 1990. Potential lifetime fecundity and the factors affecting annual fecundity in *Urodacus armatus* (Scorpiones, Scorpionidae). *J Arachnol* 18: 271-280.
- Tammaru, T., Esperk T, and Castellanos I.** 2002. No evidence of being large in females of *Orygia* spp. (Lepidoptera, Lymantriidae): larger is always better. *Oecologia* 133:430-438.
- Taylor ME, Bundy CS, McPherson JE.** 2015. Life history and laboratory rearing of *Bagrada hilaris* (Hemiptera: Heteroptera: Pentatomidae) with descriptions of immature stages. *Ann Entomol Soc Am* 108: 536-551.
- Wang CL, Chiang MY.** 1998. New record of a fastidious chrysomelid, *Ophraella communa* LeSage (Coleoptera: Chrysomelidae), in Taiwan. *Plant Prot Bull* 40: 185-188. (in Chinese)
- Watson AK, Teshler M.** 2013. *Ambrosia artemisiifolia* L., common ragweed (Asteraceae). pp. 296-300. In: Mason PG, Gillespie DR (eds.) *Biological Control Programmes in Canada 2001-2012*. CABI, Wallingford, UK.
- Xion XZ.** 1992. Laboratory rearing method and life history of *Falsogastrallus sauteri pic* (Coleoptera: Anobiidae). *Coleoptes Bull* 46: 321-324.
- Yadav R, Chang N.** 2014. Effects of temperature on the development and population growth of the melon thrips, *Thrips palmi*, on eggplant, *Solanum melongena*. *J Insect Sci* 14: 1-9.
- Zani PA, Cohnstaedt LW, Corbin D, Bradshaw WE, Holzapfel CM.** 2005. Reproductive value in a complex life cycle: heat tolerance of the pitcher-plant mosquito, *Wyeomyia smithii* *J Evol Biol* 18: 101-105.
- Zhong SZ, Rasmann S, Zheng HY, Watson A, Guo JY, Wang JG, Wan FH.** 2015. Mating frequency positively associates with fitness in *Ophraella communa*. *Ecol Entomol* 40: 292-298.
- Zhou Z, Guo J, Chen H, Wan F.** 2010. Effect of humidity on the development and fecundity of *Ophraella communa* (Coleoptera: Chrysomelidae). *Bio Con* 55: 313-319.
- Zhou Z, Wan F, Guo J.** 2017. Common ragweed *Ambrosia artemisiifolia* L. p. 99-110. In: *Biological Invasions and Its Management in China*. Vol. 2, Wang F, Jiang M, Zhan A (eds.) Springer. Springer Nature Singapore Pte Ltd.
- Zhou ZS, Chen HS, Zheng XW, Guo JY, Guo W, Li M, Luo M, Wan FH.** 2014. Control of the invasive weed *Ambrosia artemisiifolia* with *Ophraella communa* and *Epiblema strenuana*. *Biocontrol Sci Technol* 24: 950-964.
- Zhou ZS, Guo JY, Zheng HY, Wan FH.** 2012a. Effects of morphological traits, age and copulation experience on mate choice in *Ophraella communa*. *Biocontrol Sci Technol* 22: 81-91.
- Zhu DH, Zhu J, Peng ZP, Wan FH.** 2012b. Effects of photoperiod and temperature on reproductive diapause in *Ophraella communa* (Coleoptera: Chrysomelidae), a potential biocontrol agent against *Ambrosia artemisiifolia*. *Insect Sci* 19: 286-294.

溫度對豬草金花蟲 (*Ophraella communa*) (鞘翅目：金花蟲科) 在銀膠菊 (菊科) 上生活史特性之影響

陳文華^{1*}、瓦希德^{2*}、卡雷納²、曾敏南³、張萃嫻^{1**}

¹ 國立屏東科技大學植物醫學系 屏東縣內埔鄉

² 國立屏東科技大學熱帶農業暨國際合作系 屏東縣內埔鄉

³ 農業委員會高雄區農業改良場 屏東縣長治鄉

**通訊作者 email: tychang@mail.npust.edu.tw

收件日期：2019年5月5日 接受日期：2019年7月3日 線上刊登日期：2019年8月9日

摘 要

銀膠菊 (*Parthenium hysterophorus*) 為一具經濟重要性的入侵種雜草，原產於中、南美洲地區。而豬草金花蟲 (*Ophraella communa*) 是銀膠菊重要的生物性天敵，本試驗在 20、25 和 30 °C 三種不同定溫下豬草金花蟲取食銀膠菊的生長、發育等生活史進行研究，以了解豬草金花蟲取食銀膠菊的最適溫度，並確認不同定溫對豬草金花蟲生長、發育及成蟲壽命及繁殖力的影響。結果顯示，隨著溫度的升高，豬草金花蟲的發育時間逐漸縮短，但相同溫度下、雄間差異不顯著。各齡期的存活率以 25°C 時最高，而在 20°C 時為最低，且隨年齡的增加而降低；而豬草金花蟲取食銀膠菊於 25°C 時產卵量為最高，20°C 時為最低，由試驗結果顯示豬草金花蟲於 25°C 時取食銀膠菊對其生活史表現是最適合的。

關鍵詞：銀膠菊、豬草金花蟲、未成熟期、性比、溫度