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Effects of Temperature on Body Size and Reproductive Potential of *Forcipomyia* (*Lasiohelea*) *taiwana* (Shiraki) (Diptera: Ceratopogonidae)

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ABSTRACT

The biting midge, *Forcipomyia* (*Lasiohelea*) *taiwana* (Shiraki) (Diptera: Ceratopogonidae), is considered a major pest in Taiwan. Biting by the *F. taiwana* has led to reduced quality of life and has severely affected the leisure and tourism industries. It has been described that the body size of animals follows a 'temperature size rule", with warmer environments resulting in a smaller body size. In this study, we aimed to investigate the effect of larval rearing temperatures on the body size of adult *F. taiwana*. Adults of biting midge were collected from Taichung City, Changhua County, and Nantou County in central Taiwan and were used as experimental insect sources. The female body size and wing length varied significantly during different seasons. Female individuals with the shortest wing length of 0.958 ± 0.004 mm were captured during the summer solstice whereas those with the longest wings of 1.209 ± 0.003 mm were captured during the winter solstice. Furthermore, female fecundity was found to positively correlate with the wing length and body size. Body size is affected by the larval developmental temperature, which is, in turn, directly related to the wing length. In addition, when satiated with a blood meal, females *F. taiwana* individuals had a shorter ovipositional time at higher temperatures. Our results also revealed that egg maturation was faster at higher temperatures. Female *F. taiwana* individuals had higher fecundity at 25°C and 30°C compared with other temperatures. Furthermore, the ovipositional rhythm of female *F. taiwana* individuals did not vary by temperature changes.

Key words: *Forcipomyia taiwana*, wing length, body size, temperature, ovipositional rhythm

Introduction

The biting midge, *Forcipomyia* (*Lasiohelea*) *taiwana* (Shiraki) (Diptera: Ceratopogonidae), is a major hematophagous insect distributed mainly in Taiwan (Shiraki, 1913; Yeh *et al.*, 2009). Female adults bite the exposed parts of the human body, causing redness and itching (Chen *et al.*, 2005). *F. taiwana* biting is a source of annoyance and irritation to humans, leading to reduced quality of life and severely affecting the leisure and tourism industries. To date, 24

Forcipomyia species have been recorded in Taiwan, but only *F. taiwana* and *F. anabaenae* feed on human blood (Lien, 1989; 1991). Their abundance in Taiwan is ascribed to high temperatures and rainfall during the spring and summer (Chen *et al*., 1982; Lee and Hou, 1997; Chuang *et al.* 2000).

Reiskind and Zarrabi (2012) described that the body size of animals follows a "temperature size rule" in which they have a smaller body size when living in a warmer environment. Insects do not exuviate after becoming adults because of the confining exoskeleton. Therefore, the larval development temperature is the main factor that affects the body size of adults (Ciota *et al*., 2014). For example, the body size of *Aedes albopictus* (Asian tiger mosquito) in warm seasons is smaller than that in cool seasons (Alto and Juliano, 2001). Adult body size may directly affect the abundance of mosquitoes; larger female adults can consume a greater volume of blood, acquire more nutrients, and lay more eggs. In addition, larger female adults can store more energy, live longer, and have higher blood-sucking frequency. Lyimo *et al*. (1992) and Mohammed and Chadee (2011) have also stated that temperature is the important factor affecting the population density of *Ae. aegypti*.

This study focused on the effects of larval rearing temperatures on the body size of adult *F. taiwana*. We also investigated female *F. taiwana* body size variation and its influence on its fecundity during different seasons. In addition, we studied the effects of temperature on the gonotrophic cycle and fecundity of female *F. taiwana* individuals.

Materials and Methods

Relationship between seasons and the reproductive potential of *F. taiwana* adults

Female *F. taiwana* individuals were captured using the human bait method (Chuang, 1994) during the winter solstice in 2012, spring equinox 2013, summer solstice 2013, and autumnal equinox in 2013. Three sampling sites in central Taiwan were chosen: (1) Huatan Township, Changhua County (longitude, 120.559242; latitude, 24.043061); (2) Lugu Township, Nantou County (longitude, 120.785602; latitude, 23.804118); and (3) Beitun District, Taichung City (longitude, 120.750733; latitude, 24.173176). Two hundred female midge were sampled each time at every sampling site. Because *F. taiwana* is a highly anthropophilic species, the collected female adults were starved for 4 h after being taken back to the laboratory and were subsequently fed with blood on the arms of the author for 20 min, so that they could obtain sufficient blood. Thirty blood-satiated female adults were randomly selected, placed individually in paper cups containing a filter paper on moistened cotton, and provided with 10% sucrose solution. These gravid female adults were allowed to oviposit individually, and the numbers of eggs laid were counted. After completing oviposition, each female individual was dissected, and the numbers of eggs remaining in the ovary were counted. The numbers of eggs laid plus the eggs remaining in the ovary was defined as the total egg production. The wing length of each dissected female individual was also measured. The correlation between the wing length and total egg production was analyzed as a reference for investigating the reproductive potential of *F. taiwana* adults during each season.

Effects of larval rearing temperatures on adult *F. taiwana* body size

The biting midges used for this part of the study were all captured from Taichung City using the human bait method (Chuang, 1994). The captured female individuals were taken back to the laboratory, starved for 4 h, and then fed with blood from the arms of the author for 20 min. The blood-satiated female individuals were placed onto a moistened paper cup and were provided with 10% sucrose solution. Subsequently, female individuals were reared for 48 h until egg maturation; then, gravid female individuals were pooled together into an ovipositional apparatus containing filter paper on moistened cotton for egg laying and were provided with 10% sucrose solution. After oviposition for 48 h, these eggs were collected and used for further studies.

Culture of *Anabaena sp.* CH2

Cyanobacterium, *Anabaena* sp. CH2 (Chen, 1982), obtained from the Department of Life Sciences, National Chung Hsing University, was cultured in a 500-mL Erlenmeyer flask

containing 300 mL of Arnon medium with air supplied using an air pump at 25°C ± 1°C under 4,000 lux for 24 h. The suspension was cultured for 3 weeks and subsequently transferred into a 250-mL Erlenmeyer flask. After incubating at room temperature for a further 2~3 days, supernatants were removed, and residual cell pellets were used as food for the larvae being reared.

Rearing of larvae

Eggs were collected from the filter paper in the ovipositional apparatus and transferred to a 9-cm agar plate, which was then covered with a lid until the eggs hatched. Groups of newly hatched larvae were reared in incubators at 15°C, 20°C, 25°C, 30°C or 35°C, with light : dark cycles of 12 h. Larvae were fed with sufficient *Anabaena* sp. CH2 before pupation.

Measurement of adult *F. taiwana* wing length and body size

Adults were reared from larvae at different temperatures; then, every 30 pairs of adults were randomly selected from each of the different temperature regimes for measurement of their wing length. Briefly, under a dissecting microscope (Leica Microsystems Pty Ltd., Wetzlar, Germany), the right wing was carefully removed from the thorax using forceps (Mohammed and Chadee, 2011). Subsequently, the right wing was placed on a microscope slide, and its length was measured from the apical notch to the axillary margin using a micrometer (Nikon Instruments Inc., Tokyo, Japan) under the dissecting microscope.

In another assay, 200 female individuals were captured each time at every sampling site during the four seasons. Among them, 30 female individuals were randomly selected, and their wing lengths were measured individually. The onset of a metamorphic molt must be precisely controlled because metamorphosis can terminate the growth phase of a larva, establishing the body size of the adult insect (Nijhout, 1981), thereby determining the wing length. The body size of the mosquitoes is usually determined by measuring the wing length; the body size of similar insects can also be measured in this way.

Effects of temperature on gravid female individuals and oviposition

Female individuals were captured from Beitun District, Taichung City (longitude, 120.750733; latitude, 24.173176) using the human-bait method. Captured female individuals were brought back to the laboratory and provided with sufficient blood. A single individual blood-satiated female was placed into a bottle. Every 20 bottles were used as one replicate, and five replicates were considered as a group. A total of 600 bottles were used in the study. Group were incubated at 10°C, 15°C, 20°C, 25°C, 30°C or 35°C under light : dark cycles of 12 h. After being maintained in their respective incubators, the ovipositional behavior of gravid female individuals was observed and recorded every 3 h for 7 days. Females individuals were then dissected to confirm whether there were any eggs remaining in the ovaries.

Statistical analyses

One-way ANOVA was used to analyze whether there was any significant difference between the wing length of *F. taiwana* adults captured during each season and fecundity as well as the relationship between the wing length and temperature. In addition, simple linear regression was adopted to analyze the relationship between the wing length of *F. taiwana* adults and fecundity by using JMP (SAS, 2012, v.10). Statistical Products and Services Solutions (SPSS) software was used to analyze the effects of the ovipositional rhythm and temperature on oviposition. The analytical methods used included independent sample *t* test, ANOVA with post hoc and Tukey's HSD test, and regression analysis, including linear regression, multiple regression analysis, and probit analysis. Differences were considered statistically significant if the *p* value was less than 0.05.

Results

Comparison of wing lengths of field-captured female *F. taiwana* adults

The average wing length of female *F. taiwana* adults captured from central Taiwan during the winter solstice was 1.209 ± 0.003 mm,

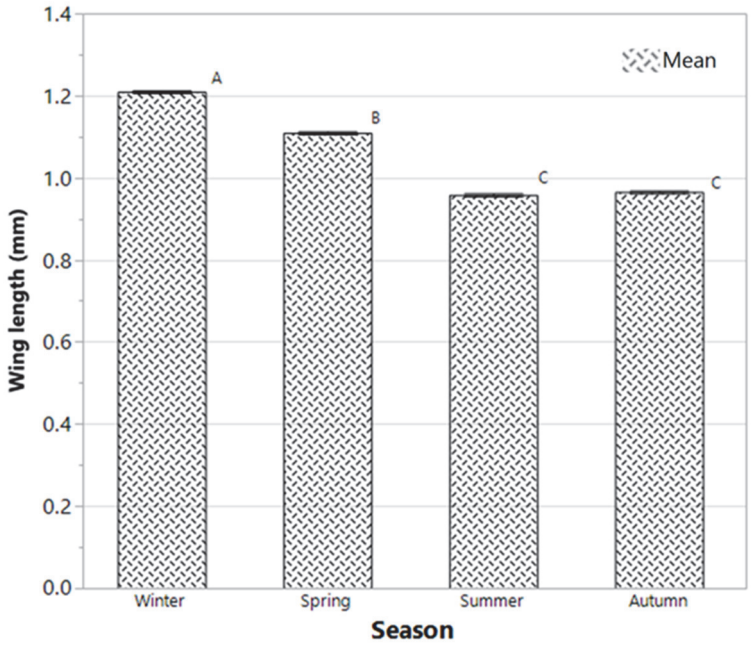

Fig. 1. Wing length of female *Forcipomyia taiwana* adults collected at three sampling sites in central Taiwan during different seasons. Error bars are the standard error of mean. The same letters denote values that are not significantly different from each other.

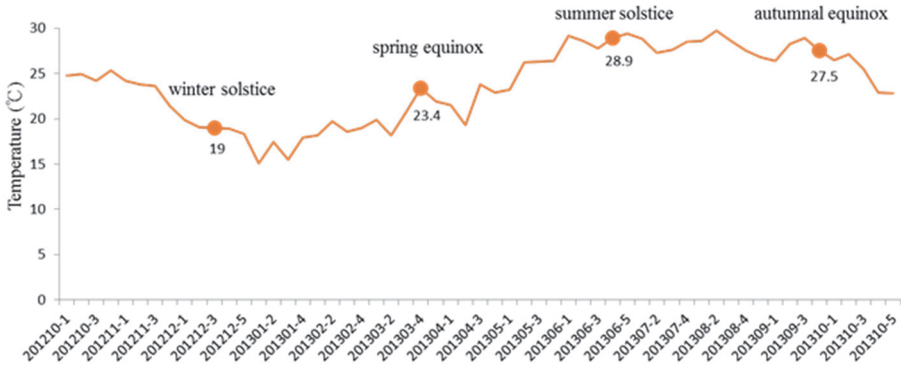

Fig. 2. Weekly average temperature in central Taiwan from October 2012 to October 2013.

with the largest body size, whereas those captured during the summer solstice had an average wing length of 0.958 ± 0.004 mm and the smallest body size. The wing length and body size of *F. taiwana* adults caught during the winter solstice were significantly bigger than those caught during summer solstice. The average wing length of *F. taiwana* adults captured during the spring equinox was 1.110 ± 0.004 mm, and their body size was between that measured during summer and winter. However, no significant difference was found in the body size of those captured during the autumnal equinox and those captured during the summer solstice (Fig. 1). The weekly average temperature and sampling time in central Taiwan during the investigation period are shown in Fig. 2.

Correlation between wing length and fecundity of field-captured female *F. taiwana* individuals

The total numbers of eggs laid by field-captured female individuals were 74.5 ± 1.3 during the winter solstice, 69.1 ± 1.5 during the spring equinox, 51.6 ± 0.8 during the autumnal equinox, and 52.8 ± 0.9 during the summer solstice. *F. taiwana* adults produced the most eggs during the winter solstice and the fewest

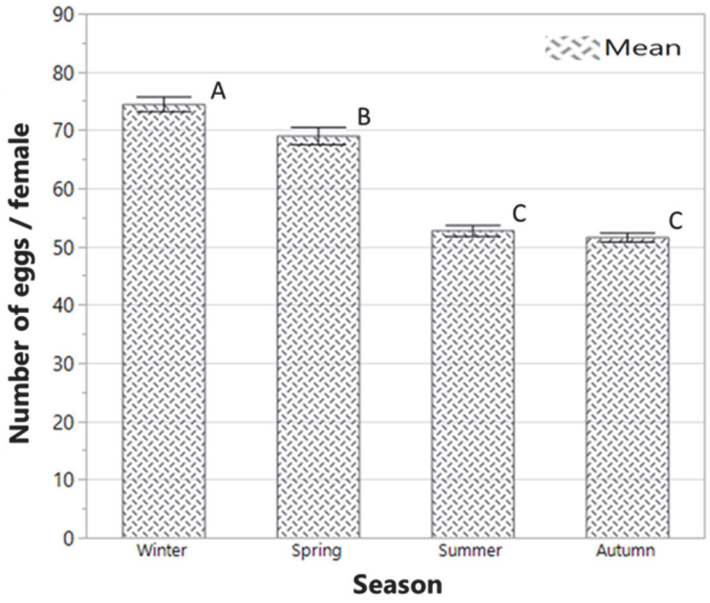

Fig. 3. Fecundity of female *Forcipomyia taiwana* adults captured at three sampling sites in central Taiwan during different seasons. Error bars are the standard error of mean. The same letters denote values that are not significantly different from each other.

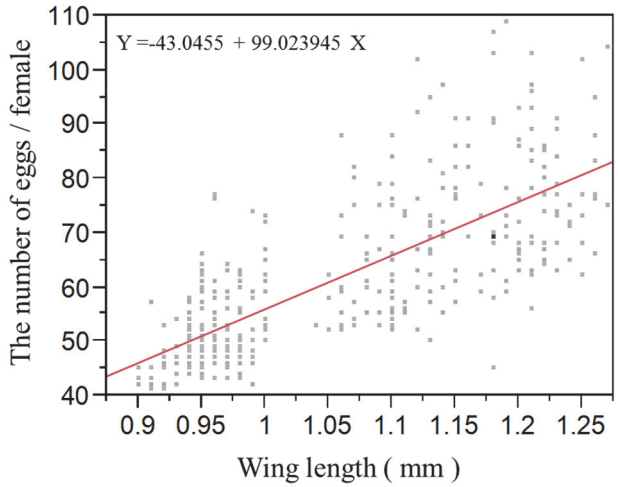

Fig. 4. Correlation of wing length and fecundity in the biting midge, *Forcipomyia taiwana*. (R^2 = 0.55, p < 0.0001)

during the autumnal equinox and summer solstice (Fig. 3). Analysis using simple linear regression showed that the wing length positively correlated with midge fecundity (R^2 = 0.55, p < 0.0001) (Fig. 4).

Effects of larval-rearing temperature on the body size of *F. taiwana* adults

The optimal temperature for the larval growth was between 20°C to 30°C, with an average survival rate of approximately 90%. Larvae did not survive at 35°C. The larval developmental time was the shortest at 30°C (approximately 10 days) and was longest at 15°C (42 days). The average wing lengths of male and female individuals at various larval-rearing temperatures were 15°C, 1.202 ± 0.005 mm (♂) and 1.053 ± 0.006 mm (♀); 20°C, 1.202 ± 0.005 mm (♂) and 1.088 ± 0.006 mm (♀); 25°C, 1.103 ± 0.004 mm (♂) and 0.957 ± 0.003 mm (♀); and 30°C, 0.970 ± 0.003 mm (♂) and 0.839 ± 0.003 mm (♀). The wing length of male individuals was longer than that of female individuals at each larval-rearing temperature. In addition, the longest wing length was observed in female individuals reared at 20°C, followed by those reared at 25°C, and the shortest wing length was observed in female individuals reared at 30°C.

Table 1. Wing length of *Forcipomyia taiwana* adults reared at various temperatures

Temp. (°C)	Male	Female
	Means ± SE[1)] (mm)	Means ± SE[1)] (mm)
15	1.202 ± 0.005 [a]	1.053 ± 0.006 [a]
20	1.202 ± 0.005 [a]	1.088 ± 0.006 [b]
25	1.103 ± 0.004 [b]	0.957 ± 0.003 [c]
30	0.970 ± 0.003 [c]	0.839 ± 0.003 [d]

[1)] The same letters indicate no significant difference among temperatures on each column within average wing length of male and female, respectively.

Table 2. Gonotrophic cycle and ovipositional rate of gravid female *Forcipomyia taiwana* adults at various temperatures

Temp. (°C)	Gonotrophic cycle (Day)	Oviposition rate of female (%)
	Means ± SE [1)]	Means ± SE
10	—[2)]	—
15	5.41 ± 0.38 [a]	9.5 ± 3.0 [c]
20	4.17 ± 0.13 [b]	32.5 ± 3.1 [b]
25	2.53 ± 0.06 [c]	67. 2 ± 3.8 [a]
30	2.14 ± 0.02 [d]	60.3 ± 5.3 [a]
35	1.88 ± 0.01[e]	1.1 ± 1.1 [c]

[1)] Means followed by the same letter within a column are not significantly different at the 5% level according to Tukey's studentized range (HSD) test.
[2)] No egg was laid.

Table 1 provides the average wing lengths of male and female individuals at each larval-rearing-temperature as well as any significant differences.

Effects of temperature on the gonotrophic cycle of gravid female individuals

Gravid female individuals of *F. taiwana* could complete egg maturation at 15°C, 20°C, 25°C, 30°C, and 35°C, with the average gonotrophic cycles being 5.41, 4.17, 2.53, 2.14, and 1.88 days, respectively (Table 2). However, female individuals incubated at 10°C failed to complete egg maturation. The length of the gonotrophic cycle increased as the temperature decreased, with the longest gonotrophic cycle being at 15°C and the shortest being at 35°C. All temperature treatments were significantly different from each other ($F_{3,146}$ = 194.150, p < 0.001).

Ovipositional rate and behavior of female *F. taiwana* individuals

The ovipositional rates of female *F. taiwana* adults were 9.5%, 32.5%, 67.2%, 60.3%, and 1.1% at 15°C, 20°C, 25°C, 30°C, and 35°C, respectively (Table 2). The highest rate was at 25°C followed by at 30°C. The ovipositional rates at 25°C and 30°C were significantly different from the other three temperatures ($F_{4,20}$ = 64.251, p < 0.001). The lowest ovipositional rate was at 35°C, which was significantly different from the rates at 20°C, 25°C, and 30°C but not significantly different from the ovipositional rate at 15°C.

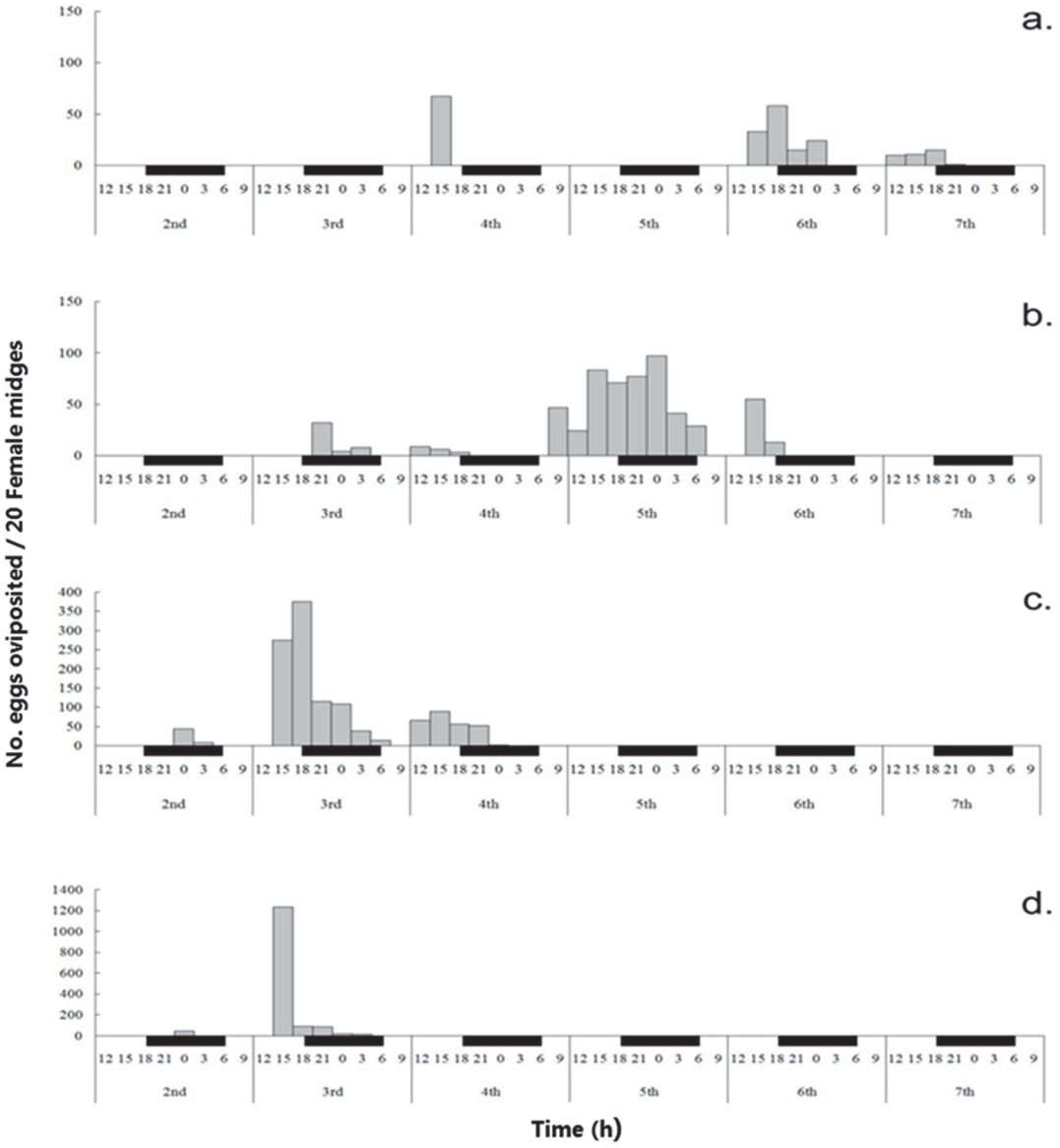

Fig. 5. Diurnal oviposition of gravid female *Forcipomyia taiwana* adults at various temperatures (a, 15°C; b, 20°C; c, 25°C; d, 30°C).

The ovipositional behavior of gravid female *F. taiwana* individuals at the same temperature regimes, as mentioned above, was also recorded. The ovipositional time increased as the temperature decreased, but fecundity decreased as the temperature decreased. At 30°C, female individuals laid all of their eggs within 3 days after being satiated with blood, whereas they took 4 days at 25°C, with a peak on the 3rd day, and they took 6 days at 20°C, with a peak on the 5th day. At 15°C, female individuals prolonged laying their eggs to the 7th day (Fig. 5). The optimal egg-laying times at each temperature regime were as follows: 30°C, 12:00~15:00, which was significantly different from other periods ($F_{7,32}$ = 44.296, p < 0.001); 25°C, 12:00~15:00 and 15:00~18:00, which was significantly different from other periods ($F_{7,32}$ = 22.924, p < 0.001). However, no significant differences were observed at 15°C and 20°C for all periods ($F_{7,32}$ = 1.792, p = 0.123, $F_{7,32}$ = 0.951, p = 0.482) (Table 3).

Discussion

Bergmann's rule is eco-geographical and states that species with a larger body size are found in colder environments, and species with a smaller body size are found in warmer environments (Huston and Wolverton, 2011).

Table 3. Diurnal oviposition of *Forcipomyia taiwana* adults at various temperatures

Temp. (°C)	No. eggs laid (Mean ± SE) [1)]							
	Time interval							
	0:00-03:00	03:00-06:00	06:00-09:00	09:00-12:00	12:00-15:00	15:00-18:00	18:00-21:00	21:00-24:00
15°C	0[a 2)]	0[a]	0[a]	2.0 ± 2.0[a]	22.2 ± 15.2[a]	14.6 ± 6.0[a]	3.2 ±1.9[a]	4.8 ± 4.8[a]
20°C	9.8 ± 7.6[a]	5.8 ± 3.7[a]	9.4 ± 9.4[a]	6.6 ± 2.2[a]	28.8 ± 11.5[a]	17.4 ± 10.6[a]	21.8 ± 11.6[a]	20.2 ± 6.0[a]
25°C	9.4 ± 2.5[c]	3.8 ± 2.7[c]	0[c]	13.2 ± 7.2[c]	72.6 ± 8.2[a]	86.2 ± 9.0[a]	32.6 ±9.0[b]	31.4 ± 9.8[b]
30°C	2.4 ± 2.4[b]	0[b]	0[b]	0[b]	243.8 ± 33.2[a]	21 ± 7.0[b]	16.8 ± 8.2[b]	13.6 ± 6.7[b]

[1)] Means with the same letter in the same row are not significantly different at $p \geq 0.05$ by Tukey's studentized range (HSD) test.

Taiwan is an island located between tropical and subtropical zones and has four distinct seasons in a year. The body size of female *F. taiwana* adults in the field varies according to the season, with those captured during the summer having the smallest body size, followed by those in spring, and those captured during the winter having the largest body size, which is in accordance with Bergmann's rule. Reiskind and Zarrabi (2012) also described that most poikilothermic animals follow a "hotter is smaller" rule when encountering temperature changes. However, our study found no significant difference in the body size of *F. taiwana* adults sampled during the summer solstice and autumnal equinox. This is because no obvious differences exist in temperature between the summer solstice and autumnal equinox in central Taiwan (Fig. 2); therefore, the body size of *F. taiwana* adults could be affected by temperature changes. However, further investigations into how much temperature changes could cause a significant difference in body size need to be conducted. The body sizes of female vector mosquitoes such as *Anopheles gambiae*, *Ae. albopictus,* and *Culex* sp., are all inversely affected by the temperature (Lyimo *et al.*, 1992; Alto and Juliano, 2001; Reiskind and Zarrabi, 2012; Ciota, 2014). Kari and Huey (2000) also pointed out that the body size of poikilothermic animals reared in the laboratory was inversely affected by the temperature.

This study is the first to investigate how the temperature at which *F. taiwana* larvae are reared affects the adult body size. Chen *et al.* (1980) found that the average wing length of female *F. taiwana* individuals was 1.04 ± 0.12 mm, and that of male individuals was 1.01 ± 0.06 mm, and Lien (1989) found the average wing length of male individuals to be 1.03 mm. Comparing with our study, the wing length of female individuals from Chen and Lien are similar with the female individuals which reared between 20°C and 25°C, and also similar with the male individuals reared between 25°C and 30°C. The average wing length of male individuals sampled by Sun (1967) was much shorter at 0.84 mm, suggesting that they were sampled above 30°C. The body size of adult insects does not change because of their exoskeleton; therefore, the larval stage determines the adult body size. Base on the temperature, during the larval stage, *Culiseta incident* (Culicidae) can change its rearing density, growth rate, and ecdysis rate, which in turn causes variation in the adult body size (Su and Mulla, 2001). In this study, female individuals of *F. taiwana* were captured at various sampling sites during different seasons and were found to have different body sizes depending on the season in which they were caught, suggesting that in nature, the temperature is an important factor that affects the adult body size.

In the current study, *F. taiwana* larvae were reared from the hatching to adult stage at different temperatures, with the optimal temperature for their development being 15°C~30°C. When larvae were reared at 20°C, the resulting adults had a large body size,

whereas larvae reared at 30°C had a small adult body size. Temperature not only influenced adult body size of *F. taiwana* but also affected the reproductive potential of the female adults. Owing to the exoskeleton barrier, the female body size directly affects the volume of blood consumed and subsequently influences their fecundity. Analysis of female wing lengths sampled during different seasons and the total egg production after a blood meal revealed that the wing length of *F. taiwana* adults positively correlated with the total egg production, indicating that female adults with a bigger body size could consume a greater volume of blood and lay more eggs. Yeh and Chuang (1996) reported that the average number of eggs produced by female *F. taiwana* individuals was 45.0 ± 17.9 eggs. Our study found that female *F. taiwana* individuals sampled during the winter solstice laid more eggs than those sampled during the summer solstice and autumnal equinox. Blackmore and Lord (2000) found that the wing length of *Ae. albopictus* positively correlated with fecundity. Similarly, fecundity of *Culex salinarius* was higher when both the body size and wing length were larger. Furthermore, high fecundity is attributed to the larger body size, rather than increased body weight (Shelton, 1972). Moreover, the same species of insect with a larger body size could have longer wing length; insects with a longer wing length can produce more eggs and have higher flight capacity. Female individuals can expand their ovipositional period, resulting in strengthening of their reproductive potential (Roff and Fairbaiirn, 1991; Sakashita *et al.*, 1995).

In our study, female *F. taiwana* individuals were incubated at various temperatures after being satiated with blood. Gravid female individuals could complete egg maturation at temperatures ranging from 15°C to 35°C, but 10°C was too low. The time required from blood-meal to oviposition was significantly affected by the temperature; as the temperature decreased, the ovipositional time increased. The time required for egg maturation was the shortest at 35°C and the longest at 15°C. Our results showed that the egg developmental rate and temperature displayed a linear correlation (R^2 = 0.9726), and each temperature treatment was significantly different from the others ($F_{3,146}$ = 194.150, $p < 0.001$), indicating that the temperature affects the gonotrophic cycle of female *F. taiwana* individuals. Furthermore, the time required to digest a blood meal is usually short, and egg maturation becomes faster at a higher temperature. Lardeux *et al.* (2008) found that the gonotrophic cycle of *Anopheles pseudopunctipennis* at 31°C was 1.8 days, but this was prolonged to 8.6 days at 15°C. Delatte *et al*. (2009) noted that at 30°C, the gonotrophic cycle of *Ae. albopictus* was 3.5 days, but this was prolonged to 8.1 days at 20°C. Mulliens and Holbrook (1991) investigated the effects of temperature on the gonotrophic cycle of *Culicoides varipennis* and found that if hematophagous insects could shorten their gonotrophic cycle, they could increase the blood-sucking frequency, thereby increasing their reproductive potential.

In this study, temperature also influenced the oviposition of female *F. taiwana* individuals; at 25°C and 30°C, the ovipositional rate increased to 67% and 60%, respectively. However, the ovipositional rates at 15°C, 20°C, and 35°C decreased significantly, and female adults did not laid any eggs at 10°C. Costa *et al*. (2010) reported that *Ae. aegypti* reduced its egg production when the temperature increased, and at 25°C with 80% relative humidity, fecundity was 40%, which was higher than that at 35°C. The time required to complete the gonotrophic cycle was mainly determined by several factors: the speed of blood digestion in the midgut, absorption and conversion of nutrients into fat body, and ovarian development; these processes could be affected by the temperature (Lindsay and Birley, 1996). In addition, a peak in the ovipositional rhythm at 30°C was observed between 12:00 and 15:00; at 25°C, there were two peaks at 12:00~15:00 and 15:00~18:00. Thus, the temperature also could affect the ovipositional rhythm of female *F. taiwana* individuals. When female individuals are satiated with blood, approximately 32.9% of gravid female *F. taiwana* individuals could not lay eggs is; however, the reason is unclear. Our study is the first report on the effects of the temperature on body size, fecundity, gonotrophic cycle, ovipositional rate, and ovipositional rhythm of in *F. taiwana*.

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References

Alto BW, Juliano SA. 2001. Precipitation and temperature effects on populations of *Aedes albopictus* (Diptera: Culicidae): Implications for rang expansion. J Med Entomol 38: 646-656.

Blackmore MS, Lord CC. 2000. The relationship between size and fecundity in *Aedes albopictus*. J Vector Ecol 25: 212-217.

Chen CS, Lien JC, Hsu SJ. 1980. Redescription and scanning electron microscopy of a bloodsucking midge, *Forcipomyia* (*Lasiohelea*) *taiwana* (Shiraki) (Diptera: Ceratopogonidae). Bull Soc Entomol, Nat'l Chung Hsing Univ 15: 211-226. (in Chinese)

Chen CS, Hsu SJ, Lien JC. 1982. Seasonal succession of a blood-sucking midge, *Forcipomyia* (*Lasiohelea*) *taiwana* (Shiraki) (Diptera: Ceratopogonidae) in the Hualien area. NTU Phytopathol Entomol 9: 68-91. (in Chinese)

Chen PC. 1982. The cultivation of native freshwater green algae and blue-green algae and its utilization value in Taiwan. J Col Sci Eng 19: 185-189. (in Chinese)

Chen YH, Lee MF, Lan JL, Chen CS, Wang HL, Hwang GY, Wu CH. 2005. Hypersensitivity to *Forcipomyia taiwana* (biting midge): clinical analysis and identification of major Fort 1, Fort 2 and Fort 3 allergens. Allergy 60: 1518-1523.

Chuang YY. 1994. The life cycle of the biting midge, *Forcipomyia* (*Lasiohelea*) *taiwana* (Shiraki) (Diptera: Ceratopogonidae) and their seasonal occurrence at Nontou area [MS Thesis]. Taichung, Taiwan: National Chung Hsing University. 52 pp. (in Chinese)

Chuang YY, Lin CS, Wang CH, Yeh CC. 2000. Distribution and seasonal occurrence of *Forcipomyia taiwana* (Diptera: Ceratopogonidae) in the Nantou area in Taiwan. J Med Entomol 37: 205-209.

Ciota AT, Matacchiero AC, Kilpatrick AM, Kramer LD. 2014. The effect of temperature on life history traits of *Culex* mosquitoes. J Med Entomol 51: 55-62.

Costa EAPA, Santos EMM, Correia JC, Albuquerque CMR. 2010. Impact of small variations in temperature and humidity on the reproductive activity and survival of *Aedes aegypti* (Diptera, Culicidae). Rev Bras Entomol 54: 488-493.

Delatte H, Gimonneau G, Triboire A, Fontenille D. 2009. Influence of temperature on immature development, survival, longevity, fecundity, and gonotrophic cycles of *Aedes albopictus*, vector of Chikungunya and Dengue in the Indian ocean. J Med Entomol 46: 33-41.

Huston MA, Wolverton S. 2011. Regulation of animal size by eNPP, Bergmann's rule and related phenomena. Ecol Monogr 81: 349-405.

Kari JS, Huey RB. 2000. Size and seasonal temperature in free-ranging *Drosophila subobscura*. J Therm Biol 25: 267-272.

Lardeux FJ, Tejerina RH, Quispe V, Chavez TK. 2008. A physiological time analysis of the duration of the gonotrophic cycle of *Anopheles pseudopunctipennis* and its implications for malaria transmission in Bolivia. Malar J 7: 141-161.

Lee SJ, Hou RF. 1997. Seasonal succession and chemical control of the biting midge (*Forcipomyia taiwana*). In: Proceedings of the 9th seminar on the control of vectors and pests; 1997 May 1-2; Taichung, Taiwan: Environmental Protection Administration, Executive Yuan, ROC. pp. 125-136. (in Chinese)

Lien JC. 1989. Taxonomic and ecological studies on the biting midges of the subgenus *Lasiohelea*, genus *Forcipomyia* from Taiwan. J Taiwan Mus 42: 37-77.

Lien JC. 1991. Seven new species and four new record of *Forcipomyia* subgenus *Lasiohelea* from Taiwan (Diptera: Ceratopogonide). J Taiwan Mus 44: 83-116.

Lindsay SW, Birley MH. 1996. Climate change and malaria transmission. Ann Trop Med

Parasitol 90: 573-588.

Lyimo EO, Takken W, Koella JC. 1992. Effect of rearing temperature and larval density on larval survival, age at pupation and adult size of *Anopheles gambiae*. Entomol Exp Appl 63: 265-271.

Mohammed A, Chadee DD. 2011. Effects of different temperature regimens on the development of *Aedes aegypti* (L.) (Diptera: Culicidae) mosquitoes. Acta Trop 119: 38-43.

Mullens BA, Holbrook FR. 1991. Temperature effects on the gonotrophic cycle of *Culicoides variipennis* (Diptera: Ceratopogonidae). J Am Mosq Control Assoc 7: 588-591.

Nijhout HF. 1981. Physiological control of molting in insects. Am Zool 21: 631-640.

Reiskind MH, Zarrabi AA. 2012. Is bigger really bigger? Differential responses to temperature in measures of body size of the mosquito, *Aedes albopictus*. J Insect Physiol 58: 911-917.

Roff DA, Fairbairn DJ. 1991. Wing dimorphisms and the evolution of migratory polymorphisms among the insect. Am Zool 31: 243-251.

Sakashita T, Fujisaki K, Nakasuji F. 1995. Environmental factors affecting wing length variation of stink bug, *Pyrrhocoris sibiricus* (Heteroptera: Pyrrhocoridae). Appl Entomol Zool 30: 303-308.

Shelton RM. 1972. The effects of blood source and quantity on production of eggs by *Culex sanlinarius* coquillett (Diptera: Culicidae). Mosq News 32: 31-37.

Shiraki T. 1913. Investigation on general injurious insects. Taiwan Sotokufu Noji Shikenjo Tokubetsu Hokodu 8: 286-296.

Su T, Mulla Mir S. 2001. Effect of temperature on development, mortality, mating and blood feeding behavior *Culiseta incidens* (Diptera: Culicidae). J Vector Ecol 26: 83-92.

Sun WKC. 1967. Study of a biting midge, *Forcipomyia* (*Lasiohelea*) *taiwana* (Shiraki) (Diptera: Ceratopogonidae). I. Description of the complete life cycle of the midge reared in the laboratory. Tunghai University, Taichung, Taiwan. Biol Bull 29: 1-10.

Yeh CC, Chuang YY. 1996. Colonization and bionomics of *Forcipomyia taiwana* (Diptera：Ceratopogonidae) in the laboratory. J Med Entomol 33: 445-448.

Yeh WB, Lee HM, Tu WC, Tang LC, Lee PY. 2009. Molecular differentiation and diversity of *Forcipomyia taiwana* (Diptera: Ceratopogonidae) based on the mitochondrial cytochrome oxidase II sequence. J Med Entomol 46: 249-256.

溫度對台灣銹蠓 (*Forcipomyia* (*Lasiohelea*) *taiwana* (Shiraki)) (Diptera: Ceratopogonidae) 體型大小與繁殖潛能之影響

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摘　要

在台灣中部地區的台中、彰化與南投等三縣市採集台灣銹蠓 (*Forcipomyia* (*Lasiohelea*) *taiwana* (Shiraki))，調查顯示雌蟲體型因季節而有變化，不同季節採集的蟲體其翅長具有顯著差異，翅長最短者為夏至採集之蟲體，平均翅長為 0.958 ± 0.004 mm，翅最長者為冬至採集的蟲體，平均翅長為 1.209 ± 0.003 mm。雌蟲翅長與卵量呈正相關性，顯示雌蟲的體型直接影響產卵量。將台灣銹蠓幼蟲飼育於不同溫度條件下，其羽化後之蟲體型大小與溫度高低具有顯著負相關，而體型大小則受幼蟲發育溫度之影響，表示幼蟲生長之環境溫度將會影響台灣銹蠓的繁殖潛能。將飽血雌蟲分別置於不同溫度條件，結果溫度愈高產卵時間愈短，顯示卵的成熟速率隨著溫度的升高而增快，其中以 25°C 與 30°C 下雌蟲的產卵量明顯高於其他溫度。雌蟲的產卵律動行為，不會因為溫度變化而有所改變。

關鍵詞：台灣銹蠓、翅長、體型、溫度、產卵律動