

圖二 不同恆溫下 *P. fletcheri* 雌寄生蜂的累計平均子代數。

Fig. 2. Number of accumulated progeny produced by *P. fletcheri* female parasitoids at various ages when held at 18, 23, and 28°C. Color solid lines (green line: 18°C, red line: 23°C, and blue line: 28°C) indicated correlation between the mean accumulated progeny and female age when held at various temperature conditions.

df=2, 12; $p=0.0022$) ; 在 1~10 日齡期間，三者分別為 14.8、34.7 及 18.6 隻 ($F=8.35$; df=2, 27; $p=0.0015$) ; 在 1~15 日齡期間，三者分別為 22.7、46.1 及 27.6 隻 ($F=7.84$; df=2, 42; $p=0.0013$) ; 在 1~17 日齡期間，三者分別為 25.9、50.7 及 31.1 隻 ($F=7.8$; df=2, 48; $p=0.0012$) (表一)。

三、*Psytalia fletcheri* 雌寄生蜂在不同恆溫下的存活率

在 18、23、28 及 33°C 等 4 種恆溫下，*P. fletcheri* 雌寄生蜂隨日齡增加之存活率經迴歸分析，結果分別可得 $y=-3.1457x + 111.97$ ($R^2=0.9629$)、

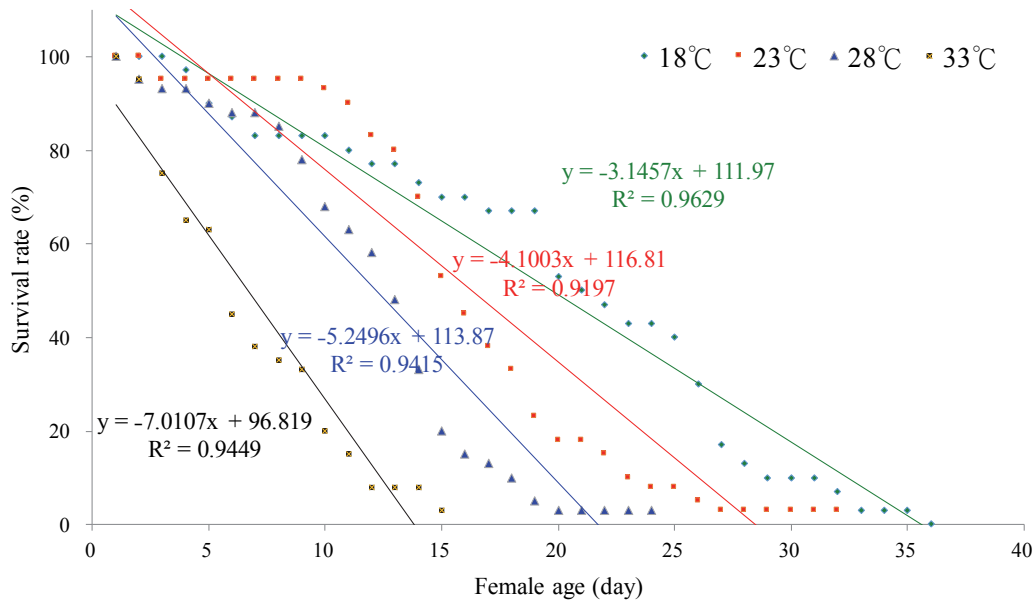
$y=-4.1003x + 116.81$ ($R^2=0.9197$)、 $y=-5.2496x + 113.87$ ($R^2=0.9415$) 及 $y=-7.0107x + 96.819$ ($R^2=0.9449$) 等四組迴歸方程式 (圖三)。選取雌寄生蜂具寄生能力的 3 種恆溫條件之迴歸線進行分析，經檢定後均為常態分布，後續分別將 1~5、1~10、1~15 及 1~17 等 4 種日齡區間代入三組方程式後，再經 one-way ANOVA 及 HSD test 檢定後，結果顯示分別在 4 種日齡區間，各恆溫存活率迴歸線的平均值間均無顯著差異。18、23 及 28°C 在 1~5 日齡期間，平均存活率分別為 86.5、87.7 及 81.3% ($F=1.31$; df=2, 12; $p=0.3069$) ; 在 1~10 日齡期間，平均存活率分別為 77.8、77.2 及 69.7% ($F=1.39$;

表一 不同恆溫下 *Psytalia fletcheri* 雌寄生蜂不同日齡累計平均子代數迴歸分析比較

Table 1. Regression analysis of accumulated progeny (means \pm SE) produced by *P. fletcheri* female parasitoids at various age periods

Temperature (°C)	Accumulated progeny (means \pm SE) followed regression equation			
	Female age periods			
	1 - 5	1 - 10	1 - 15	1 - 17
18	6.9 \pm 2.2 ^b	14.8 \pm 3.0 ^b	22.7 \pm 3.7 ^b	25.9 \pm 3.9 ^b
23	23.3 \pm 3.3 ^a	34.7 \pm 4.4 ^a	46.1 \pm 5.3 ^a	50.7 \pm 5.6 ^a
28	9.7 \pm 2.5 ^b	18.6 \pm 3.4 ^b	27.6 \pm 4.1 ^b	31.1 \pm 4.4 ^b

Within each column, mean values followed by the same letters are not significantly different (ANOVA, Tukey's HSD test at $p=0.05$)



圖三 三種恆溫下 *P. fletcheri* 雌寄生蜂各日齡的存活率。

Fig. 3. Survival rate of *P. fletcheri* female parasitoids at various ages. Color solid lines (green line: 18°C, red line: 23°C, and blue line: 28°C) indicate a correlation between the survival rate and female age when held at various temperature conditions.

df=2, 27; $p=0.2672$); 在 1~15 日齡期間, 平均存活率分別為 71.1、69.1 及 60.6% ($F=1.94$; df=2, 42; $p=0.156$); 在 1~17 日齡期間, 平均存活率分別為 68.7、66.2 及 57.2% ($F=2.24$; df=2, 48; $p=0.1178$) (表二)。

四、*Psytalia fletcheri* 子代在不同恆溫下的發育時間與雌雄比

寄生蜂子代發育時間隨著溫度升高而縮短, 在 18、23 及 28°C 時, 完成發育後羽化為雌、雄寄生蜂的時間分別均呈現顯著差異, 雌寄生蜂之發育期分別為 36.0 ± 0.2 、 20.3 ± 0.1 及 15.8 ± 0.3 日 ($F=1917.26$; df=2, 9; $p<0.0001$); 而雄寄生蜂之發育期分別為 34.3 ± 0.1 、 19.3 ± 0.1 及 15.0 ± 0.4 日 ($F=1667.85$; df=2, 9; $p<0.0001$)。而在 18、23、28°C 等 3 種恆溫環境下, 產出雌性子代寄生蜂分別為雄性子代的 2.3 ± 0.4 、 2.3 ± 0.1 及 2.2 ± 0.1 倍, 三者間則無顯著差異 ($p>0.05$) (表三)。

討 論

溫度為影響膜翅目寄生蜂 (hymenopterous parasitoids) 寄生能力與子代發育的關鍵因子, 亦

關係到室內大量繁殖的效率 (Wong and Ramadan, 1992; Jones and Stephen, 1994; Miller, 1996; Appiah *et al.*, 2013; Zhang *et al.*, 2016)。Wong and Ramadan (1992) 曾於室內 26°C (> 60% RH) 定溫條件下, 探討 *P. fletcheri* 不同日齡雌寄生蜂與繁殖能力的相關性, 結果顯示雌寄生蜂羽化後第 5 日齡 (該研究並未進行 1~4 日齡之測試) 相較後續日齡具有較高的寄生能力。但我們於 *P. fletcheri* 繼代飼育的過程 (23°C) 中, 發現寄生蜂羽化後第 2 日齡起, 即陸續出現雌、雄寄生蜂交尾行為, 而從本研究不同恆溫下寄生能力的測試結果更證實, 在 18、23 及 28°C 等 3 種恆溫下, 雌寄生蜂均自第 2 日齡起, 即可成功寄生瓜實蠅的幼蟲也產出子代, 顯示雌寄生蜂的卵巢發育亦相當迅速, 估計產卵前期 (preoviposition period) 少於 48 h, 此特性相當適合將已遭受其寄生的寄主蛹體運送到防治釋放地點, 若能配合 Vargas *et al.* (2012) 所研發技術於田間釋放地點設置圓柱形網籠, 提供剛羽化寄生蜂充足的水、碳水化合物等食物, 及提升交尾機會, 2 日 (48 h) 後應隨即可應用於田間發揮寄生效能, 除了可減輕運送過程空間的負擔及減少蟲體死亡風險, 更可提升寄生蜂羽化後存活與發揮有效寄生效能。

表二 不同恆溫下 *Psytalia fletcheri* 雌寄生蜂不同日齡存活率迴歸分析比較Table 2. Regression analysis of the survival rate (means \pm SE) of *P. fletcheri* females at various age periods

Temperature (°C)	Survival rate (means \pm SE) (%) followed by regression equation			
	Female age periods			
	1 – 5	1 – 10	1 – 15	1 – 17
18	86.5 \pm 2.3 ^a	77.8 \pm 3.2 ^a	71.1 \pm 3.3 ^a	68.7 \pm 3.4 ^a
23	87.7 \pm 2.3 ^a	77.2 \pm 3.8 ^a	69.1 \pm 4.0 ^a	66.2 \pm 4.0 ^a
28	81.3 \pm 4.1 ^a	69.7 \pm 4.4 ^a	60.6 \pm 4.5 ^a	57.2 \pm 4.6 ^a

Within each column, mean values followed by the same letters are not significantly different (ANOVA, Tukey's HSD test at $p=0.05$).

表三 不同恆溫下 *Psytalia fletcheri* 子代發育時間與雌雄性比Table 3. Developmental time and sex ratio of *P. fletcheri* progeny

Temperature (°C)	Developmental time (days) of progeny (mean \pm SE)		Sex ratio of progeny (Female/male)
	Male	Female	
	18	34.3 \pm 0.1 ^a	36.0 \pm 0.2 ^a
23	19.3 \pm 0.1 ^b	20.3 \pm 0.1 ^b	2.3 \pm 0.1 ^a
28	15.0 \pm 0.4 ^c	15.8 \pm 0.3 ^c	2.2 \pm 0.1 ^a

Within each column, mean values followed by the same letters are not significantly different (ANOVA, Tukey's HSD test at $p=0.05$).

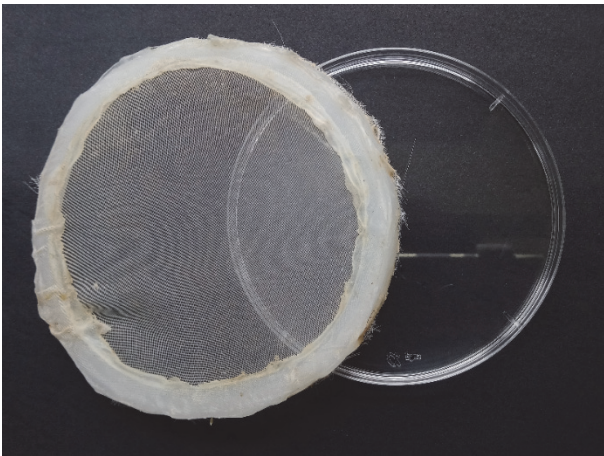
從雌寄生蜂的日齡-累計子代數迴歸分析中，我們發現在 3 種恆溫模式下，所得迴歸線的決定係數 (coefficient of determination) R^2 值均 >0.9 ，顯示應用此迴歸分析模式可合理判斷雌寄生蜂隨日齡之繁殖潛能的趨勢，當比較 3 種恆溫模式的回歸線時，則發現在 1~5、1~10、1~15 及 1~17 等 4 種日齡區間，23°C 時雌寄生蜂均具有顯著較高的累計子代數 ($p<0.05$)；此外，從雌寄生蜂不同日齡之存活率分析，所得之日齡-存活率迴歸線在 3 種恆溫模式下的 R^2 值亦均 >0.9 ，顯示此等存活率迴歸線亦可合理判斷雌寄生蜂在不同溫度下的存活表現，然而，比較 3 種恆溫模式的存活率迴歸線時，則發現在 1~5、1~10、1~15 及 1~17 等 4 種日齡區間，3 種溫度間呈現無顯著差異 ($p>0.05$)。另以各恆溫下雌寄生蜂的平均壽命日數，代入各溫度累計子代數迴歸方程式中，估算雌寄生蜂平均一生可產子代總數，在 18、23 及 28°C 等 3 個溫度時，分別可產出 62.0、85.8 及 43.7 隻子代，亦顯示在 23°C 時最具繁殖潛能。因此，綜合固定日齡期間或一生總子代數二種判斷模式，室內大量飼育時，建議以 23°C 建構飼育環境，可獲取最多子代數量，但考量子代發育時間，則可將已被寄生之瓜實蠅幼蟲或蛹體移置 28°C 環境，縮短寄生蜂幼蟲期發育時間，以在最短時程內獲得最多子代寄生蜂。

溫度條件是田間應用寄生蜂生物防治的最重要

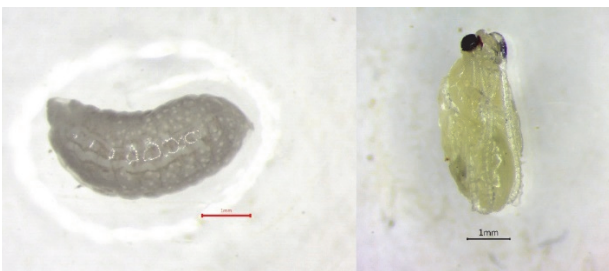
因素之一 (Loni, 1997; Appiah *et al.*, 2013)，且近年來因應未來氣候變遷的研究，亦常聚焦於模擬溫度變化對寄生蜂與寄主的影響，而二者在溫度條件的同步性 (synchrony) 更是探討重點 (Hance *et al.*, 2007; Kant *et al.*, 2012; Romo and Tylianakis, 2013; Gebauer *et al.*, 2015)。從適合瓜實蠅發育與瓜類生長的角度評估，可發現瓜實蠅適合繁殖的溫度為 24~29°C (Vargas *et al.*, 1997)，而多種瓜類作物適合栽培的溫度範圍為 65~85°F ($\approx 18.3\sim 29.4^\circ\text{C}$) (Maynard and Hochmuth, 2007)，適合寄主植物生長與害蟲繁殖的溫度範圍同步性極高，因此，不難想像瓜類種植期間遭受瓜實蠅攻擊的高風險性。田間欲應用寄生蜂進行瓜實蠅的生物防治時，亦需考量雌寄生蜂在此等溫度環境間的適用性，而從本試驗測試 *P. fletcheri* 雌寄生蜂在 18、23 及 28°C 等 3 種恆溫度狀況下的寄生與存活表現，均發現雌寄生蜂在無顯著差異的存活率下，均可發揮寄生瓜實蠅幼蟲之效能，且在 23°C 環境時則更具有提升寄生效能的應用價值。因此，考量適合瓜類作物生長、瓜實蠅發育繁殖及寄生蜂發揮寄生能力三者最適溫度範圍的同步性，此寄生蜂具備在瓜類種植期間應用於瓜實蠅生物防治之潛力。

相當多文獻記載 *P. fletcheri* 應用於瓜實蠅生物防治的重要性，但有關室內大量飼育之研究，除了

確定瓜實蠅第 3 齡初期幼蟲為其較適合之寄生齡期，及適當供其寄生裝置與技術之改良外，均以恆溫環境進行大量飼育，而未曾針對此寄生蜂與溫度間的相關性進行探討 (Willard, 1920; Nishida, 1955; Wong and Ramadan, 1992; Bautista *et al.*, 2000; Vargas *et al.*, 2004, 2008, 2012; Harris *et al.*, 2010)。本研究模擬恆溫環境下的試驗結果，應用迴歸分析探討各溫度下存活率及累計子代數 (繁殖潛能) 間的差異，及配合子代發育時間的分析，除了可提供室內飼育 *P. fletcheri* 時，作為縮短時程獲取最多子代之參考，亦可於田間防治瓜實蠅時，作為配合田間溫度條件提升此寄生蜂發揮最大防治潛能之參考。



附圖一 寄生用培養皿。
Appendix Fig. 1 Oviposition equipment.



附圖二 *Psytalia fletcheri* 的幼蟲及蛹。
Appendix Fig. 2 Larva (left) and pupa (right) of *P. fletcheri*.

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Effects of Constant Temperatures on Survival Rate and Parasitism of a Specialist Larval Parasitoid *Psytalia fletcheri* (Hymenoptera: Braconidae) in *Zeugodacus cucurbitae* (Diptera: Tephritidae)

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ABSTRACT

In this study, we evaluated the survival rate, parasitism, and progeny development time of a melon fly larval endoparasitoid, *Psytalia fletcheri* (Silvestri) (Hymenoptera: Braconidae) held at four constant temperatures (18, 23, 28, and 33°C). The mean longevity for male and female parasitoids was recorded at 18°C, which were 20.3 ± 8.9 and 18.7 ± 9.5 days, respectively. No significant difference was observed between the mean values obtained at 18°C and 23°C; however, longevity was shorter at 28 and 33°C than at 18 and 23°C. Female parasitoids produced offspring from the second day at 18, 23, and 28 °C. No progeny was recorded for female parasitoids at 33°C. The mean total number of progeny produced per *P. fletcheri* female parasitoid (85.8) was significantly higher at 23°C than at the other two temperatures according to the results of the regression analysis of accumulated progeny. Progeny development time decreased with increasing temperatures, with mean values of 36.0 ± 0.2 , 20.3 ± 0.1 , and 15.8 ± 0.3 for female parasitoids when reared at 18, 23, and 28°C, respectively. Progeny development time differed significantly among the temperatures. The results of this study can be applied to mass rearing or integrating field temperature for the biological control of melon fly.

Key words: *Zeugodacus cucurbitae*, *Psytalia fletcheri*, temperature, survival rate, parasitism