

Effect of Temperature on Prey Consumption Rate of the Green Lacewing *Mallada basalis* (Walker) (Neuroptera: Chrysopidae) to Two Species of Pest Mites, *Tetranychus kanzawai* Kishida and *Panonychus citri* (McGregor) (Acari: Tetranychidae)¹

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Abstract

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The green lacewing, *Mallada basalis*, has been shown to have high potential as a biological control agent against two mite species of economic importance on papaya: the Kanzawa mite, *Tetranychus kanzawai*, and the citrus mite, *Panonychus citri*. However, the impact that this predator can have on mite populations is dependent on prevailing environmental temperatures, which influence predator-prey dynamics by affecting developmental rate, survival, reproduction, and longevity. Another effect of temperature, which this study investigated, is predator consumption rate. We measured the consumption rates of 2nd instar *M. basalis* on *T. kanzawai* and *P. citri* at five temperatures (15, 20, 25, 30, and 35°C) in the laboratory. Results indicated that prey consumption by 2nd instar lacewings was temperature-dependent, increasing between 15 and 30°C for both mite species; however, consumption declined at 35°C. Numbers of *T. kanzawai* nymphs consumed in a 30-min trial ranged from 16.3 ± 1.0 at 15°C to 45.7 ± 2.5 at 30°C. On *P. citri*, predators consumed 26.4 ± 1.8 nymphs at 15°C and 48.0 ± 3.3 at 30°C. There were slightly different trends in the consumption rate of the lacewing in response to the five temperatures between the two mites, and this might be the result of the different spatial distribution patterns of the two mites as well as different handling times of the lacewing for the two

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mites. High prey consumption rates across a wide temperature range, including temperatures as low as 15°C, suggest that *M. basalis* may be suitable for year-round application in Taiwan against both *T. kanzawai* and *P. citri*. However, further investigations on the effect of temperature on the predatory potential of *M. basalis* under field conditions are needed for effective application of this lacewing in papaya mite management programs.

Key words: Phytophagous mites, Predator-prey interaction, Feeding behavior, Predation rate, Biological control.

The Kanzawa spider mite, *Tetranychus kanzawai* Kishida, and the citrus red mite, *Panonychus citri* (McGregor), are two important acarine pests of a wide range of crops in many parts of the world (Bolland *et al.* 1998; Zhang 2003). They cause injury by penetrating plant tissue with their stylets to feed on cell chloroplasts. This results in leaf stippling, wilting, and defoliation, which ultimately reduces plant growth and productivity. Intensive application of miticides, combined with short life cycle and strong fertility of the mites, have led to the development of resistance to most registered miticides (Furuhashi 1994; Masui *et al.* 1995; Goka 1998; Aiki *et al.* 2005). Therefore, the search for alternative control measures has become essential.

Mallada basalis (Walker) is a common chrysopid in agricultural fields in Taiwan. Previous investigations have suggested its potential for controlling several species of arthropods. These include *Phyllocnistis citrella* Stainton, *Aphis* spp., *Nipaecoccus filamentosus* (Cockerell), *Diaphorina citri* Kuwayama, and *P. citri* on citrus; *T. urticae* Koch and *T. kanzawai* on strawberry; and *P. citri* on Indian jujube (Hao *et al.* 1996; Lo 1997; Hao 2002). A further benefit is that *M. basalis* can be mass-produced on a microcapsulated artificial diet in a cost-effective manner (Lee 1995, 2003). In addition, cold storage techniques have been established to store immature life stages for shipment and scheduled releases (Wu 1992). Finally, research has demonstrated tolerance in *M. basalis* to some insecticides, fungicides, and acaricides (Tzeng & Kao 1996; Lo 2002). All of these suggest that *M. basalis* is very compatible for use in integrated pest management.

Our earlier studies have provided further support that *M. basalis* has high potential as a biological control agent for both *T. kanzawai* and *P. citri* on papaya (Cheng *et al.* 2009, 2010, 2012). However, one factor that has not been investigated is how

temperature influences predator-prey interactions between *M. basalis* and papaya mites. In general, temperature plays a crucial role in the bionomics of insects. Numerous studies have demonstrated effects of temperature on natural enemy development and population growth (Obrycki & Tauber 1982; Tauber *et al.* 1987; Lopez-Arroyo *et al.* 1999; Pervez 2004), as well as on foraging behavior, functional response, and predation capability (Runjie *et al.* 1996; Nielsen 1999; Mohaghegh *et al.* 2001; Flinn & Hagstrum 2002; Mahdian *et al.* 2006; Parajulee *et al.* 2006). This study investigated the effect of temperature on the consumption rate of *M. basalis* to two species of pest mites, *T. kanzawai* and *P. citri*, to provide information for understanding and effectively applying *M. basalis* in augmentative biological control programs for these two pest mites.

A laboratory colony of *M. basalis* was used for this study. This colony has been reared continuously, with no introduction of wild individual, since 1999 at 26 ± 2°C, 70 ± 10% RH and a photoperiod of 14:10 (L:D) on microcapsulated artificial diets developed for larvae (Lee 1994, 1995), and a Brewer's yeast and honey (1:1) diet for adults following the procedures described in Cheng *et al.* (2009). *T. kanzawai* and *P. citri* were collected from the papaya plantations in Nantou areas, and maintained on papaya seedlings at 26 ± 2°C, 70 ± 10% RH and a photoperiod of 14:10 (L:D) in separate rearing rooms. Papaya seedlings (*Carica papaya* L., 'Tainung No. 2') used for rearing the mites were purchased from a commercial nursery 3–4 weeks after germination. The seedlings were then transferred individually to 9-cm diameter pots, and maintained in a room at 26 ± 2°C, 70 ± 10% RH and a photoperiod of 14:10 (L:D) until they were approximately 25 cm tall and suitable for rearing mites. The seedlings were watered twice a week, but without any fertilization. For carrying out the experiments, a piece of papaya leaf

(~470 mm²) with the undersurface facing up was floated on water (~4 mL) in a 5-cm diameter Petri dish. One hundred mite nymphs (either *T. kanzawai* or *P. citri*) were introduced onto the leaf and the unit was then placed in a growth chamber at 70 ± 10% RH and one of the following temperatures: 15, 20, 25, 30 and 35°C. One green lacewing second instar larva (at their 2nd day) which had been starved and kept in the growth chamber for 4 h prior to the test was then added onto the leaf in the Petri dish. The Petri dish was then covered with the lid. Thirty minutes later, the number of the mites consumed by the lacewing was recorded. Tests for each mite species and at each temperature were replicated at least 20 times. Because of a limited number of growth chambers, tests were blocked over time and the order was randomized for each block. Data were analyzed using the Kruskal-Wallis test because of non-normality of data distribution. Significantly different means were separated with Fisher's protected LSD procedures, with the significance level set at $P < 0.05$. All analyses were conducted using STATGRAPHICS Centurion XV software (StatPoint, Herndon, VA).

Results showed that prey consumption by 2nd instar *M. basalis* increased between 15 and 30°C, and then declined between 30 and 35°C on both *T. kanzawai* and *P. citri* (Table 1). Except at the highest temperature (35°C), consumption was consistently higher on *P. citri* than on *T. kanzawai*. On *T. kanzawai*, the lacewing exhibited a statistically nonsignificant prey consumption rate between 15 and 20°C (mean separation = 7.1; LSD = 7.8). Consumption then in-

creased significantly with increasing temperature to 30°C ($H = 47.05$; $df = 99$; $P < 0.0001$). Whereas on *P. citri*, the lacewing's prey consumption rate at 20°C was significantly higher than at 15°C (mean separation = 9.0; LSD = 8.15), but was similar between 20 and 25°C. Consumption then increased significantly between 25 and 30°C. In both species, the consumption rate decreased between 30 and 35°C, but the difference was only significant in *P. citri* (mean separation = 9.1; LSD = 8.15). The slightly different trend in consumption rate of *M. basalis* in response to temperature between the two mites may be due to the different spatial distribution patterns of the two mites, as well as the different handling times of the lacewing to the two mites (Cheng *et al.* 2009). *T. kanzawai* has a clumped distribution, but *P. citri* is more evenly distributed. This difference in spatial distribution between these two mite species is quite significant. At the lower temperature (e.g., 15°C), the lacewing might have a lower mobility. The effect of temperature on the lacewing's consumption rate might be less pronounced with species that have a clumped distribution because the lacewing does not have to move much to forage. This would assume that movement is limited to a greater degree by low temperature than prey handling. In an earlier study, we had demonstrated that the handling time of *M. basalis* with *P. citri* was shorter than with *T. kanzawai* (Cheng *et al.* 2009). Thus, at higher temperatures (e.g., between 30 and 35°C), the comparatively shorter handling times might make the effect of temperature on the consumption rate of *M. basalis* more pronounced with *P. citri*. The shorter handling time might also provide an explanation for the higher consumption rate of *P. citri* compared with *T. kanzawai* in this study. In addition, the effect of temperature on predator metabolism may also play a role in the consumption rates among various temperatures.

A number of studies have shown the relationship between temperature and various responses in predators, including green lacewings (Nee 1983; Ding & Chen 1986; Tauber *et al.* 1987; Nielsen 1999; Pervez 2004; Parajulee *et al.* 2006). For natural enemies in general, it has been suggested that increased feeding activity and search rates at high temperatures, as well as decreased handling times, enhance the functional response and, thus, have important impacts on the potential of natural enemies

Table 1. Prey consumption of *Mallada basalis* second instar larvae to *Tetranychus kanzawai* and *Panonychus citri* nymphs at various temperatures (total duration = 30 minutes) ($n = 20$)

Temperature (°C)	Mean (± SEM) number mites consumed	
	<i>T. kanzawai</i>	<i>P. citri</i>
15	16.3 ± 1.0 a ^z	26.4 ± 1.8 a
20	23.5 ± 1.9 a	35.4 ± 2.8 b
25	34.3 ± 2.4 b	37.5 ± 3.5 b
30	45.7 ± 2.5 c	48.0 ± 3.3 c
35	38.8 ± 4.7 bc	38.9 ± 2.9 b

^z Means within the same column followed by the same letter are not significantly different at $P < 0.05$ (LSD = 7.80 and 8.15 for *T. kanzawai* and *P. citri*, respectively) (Fisher's protected LSD test; STATGRAPHICS Centurion XV, 2005).

to control target pests (Runjie *et al.* 1996; Mohaghgh *et al.* 2001; Flinn & Hagstrum 2002; Mahdian *et al.* 2006; Parajulee *et al.* 2006).

In a study with *M. basalis*, Chang (2000) indicated that the effective temperature range for larvae is about 15 to 43°C. The current study demonstrated that prey consumption by *M. basalis* increased within a narrower range of temperature, and that temperatures above 30°C were not optimal for prey consumption. Although *M. basalis* exhibited lower predation rates at the lower temperatures of 15 and 20°C, at these temperatures both pest mites also have lower developmental rates. While *P. citri* has an optimal population growth rate at 25°C (Zhang 2003), and *T. kanzawai* at 34°C (Chang 2000), *M. basalis* showed increased predation rates at these temperatures. Our earlier studies have provided further support that *M. basalis* has strong potential as a biological control agent against both *T. kanzawai* and *P. citri* (Cheng *et al.* 2009, 2010, 2012). Based on the current study, it would appear that *M. basalis* is suitable for year-round application in Taiwan because mean monthly temperatures in Taiwan range between 16 and 30°C. However, our tests were conducted in small arenas and over a short period. Effects of temperature on the predator's search rate and the prey's ability to escape predation, and effects of prey spatial distribution on the predator's foraging efficiency, would be more prominent in field conditions. In addition, temperature fluctuations in the field may affect predator responses differently than the constant temperature conditions used for the laboratory investigation. Therefore, how temperature would affect the overall predatory potential of *M. basalis* in the field needs further investigation before this natural enemy can be effectively applied in pest management programs against mites.

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溫度對基徵草蛉 *Mallada basalis* (Neuroptera: Chrysopidae) 捕食神澤氏葉蟎 *Tetranychus kanzawai* 與柑桔葉蟎 *Panonychus citri* (Acari: Tetranychidae) 速率之影響¹

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摘 要

鄭玲蘭、James R. Nechols、David C. Margolies、James F. Campbell、楊平世、盧秋通、陳健忠。2012。溫度對基徵草蛉 *Mallada basalis* (Neuroptera: Chrysopidae) 捕食神澤氏葉蟎 *Tetranychus kanzawai* 與柑桔葉蟎 *Panonychus citri* (Acari: Tetranychidae) 速率之影響。台灣農業研究 61:158-164。

基徵草蛉 (*Mallada basalis*) 對神澤氏葉蟎 (*Tetranychus kanzawai*) 和柑桔葉蟎 (*Panonychus citri*) 兩種木瓜重要害蟎具有防治潛力，然而溫度會影響昆蟲的生長速率、存活、生殖和壽命，進而影響捕食性昆蟲與其獵物間的族群變動，因此溫度對草蛉壓制葉蟎族群之效能可產生重大影響。此外，溫度也會影響捕食性天敵對害蟲的捕食速率，本研究乃於實驗室內測定基徵草蛉於 5 種溫度下 (15、20、25、30 和 35°C) 對神澤氏葉蟎與柑桔葉蟎的捕食速率。試驗結果顯示基徵草蛉對兩種葉蟎之捕食速率於 15 至 30°C 間隨溫度升高而增加，而溫度達 35°C 捕食速率即降低。基徵草蛉之二齡幼蟲於 15°C 下 30 分鐘內可捕食 16.3 ± 1.0 隻神澤氏葉蟎之若蟎或 26.4 ± 1.8 隻柑桔葉蟎之若蟎，而於 30°C 下可捕食 45.7 ± 2.5 隻神澤氏葉蟎之若蟎或 48.0 ± 3.3 隻柑桔葉蟎之若蟎。基徵草蛉於 5 種試驗溫度下之捕食速率趨勢於兩種葉蟎間略有差異，可能與兩種葉蟎在木瓜葉片上有不同的空間分布，以及草蛉捕食兩種葉蟎所需的獵物處理時間 (handling time) 不同有關。基徵草蛉在廣泛的溫度範圍中對兩種葉蟎皆具極高的捕食效率，即使在 15°C 的低溫下亦同，顯示基徵草蛉在台灣具有終年應用的潛力，但實際應用策略的擬訂仍待進一步田間試驗的評估。

關鍵詞：葉蟎、捕食性昆蟲-獵物交互作用、取食行為、捕食速率、生物防治。

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