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Using the Green Lacewing *Mallada basalis* (Walker) (Neuroptera: Chrysopidae) to Control *Tetranychus kanzawai* Kishida (Acari: Tetranychidae) on Papaya in a Screenhouse

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Abstract

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Mallada basalis (Walker) is a generalist predator commonly found in agricultural fields in Taiwan, and is commercially available as a biological control product. A number of field investigations have indicated the potential of *M. basalis* as a biological control agent against several arthropod pest species; however, none have been carried out on pests of papayas. Likewise, there is no information on the fate of lacewing populations following their release in the field. This study investigated the feasibility of using *M. basalis* to control the primary acarine pest, *Tetranychus kanzawai* Kishida, on papaya in a screenhouse. The main objectives included determining optimal lacewing release rates, post-release population dynamics, and efficacy in controlling mites on papaya. Lacewings released at a rate of 200 eggs per plant during the summer reduced *T. kanzawai* populations by 95% on average. Mite populations were lower during the winter and required half the summer lacewing release rate to achieve the same level of control. The impact of *M. basalis* on *T. kanzawai* was similar on various life stages of the mite, both sides of the papaya leaves, and throughout the canopy regardless of leaf strata. Lacewing egg hatch success following release in a screenhouse exceeded 70%. However, subsequent larval densities rapidly declined to less than 5 per papaya plant during our weekly censuses. Lacewing populations did not accumulate through successive releases suggesting that conditions in the papaya screenhouse were not favorable for *M. basalis* development or establishment. Although sustained population of *M. basalis* could not be established in the papaya screenhouse, inundative releases of *M. basalis* at a rate of 100 to 200 eggs per plant depending on the season could be applicable as a biological means to control *T. kanzawai* on papaya in screenhouses.

Key words: *Tetranychus kanzawai*, *Mallada basalis*, Biological control, Inundative release, Papaya.

INTRODUCTION

Papaya, *Carica papaya* L., is an important fruit crop in Taiwan with annual production estimated at about 130,000 tons (Anonymous

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2012). The principal cultivated papaya variety in Taiwan is 'Tainung No. 2' (Wang 1991). However, this cultivar is susceptible to the papaya ringspot potyvirus (Lin *et al*. 1989), one of the most destructive diseases of papaya (Purcifull *et al*. 1984). Most papayas in Taiwan are now grown in screenhouses to be protected from aphids, which serve as vectors for papaya ringspot virus. Nevertheless, the unventilated, warm conditions in screenhouses favor outbreaks of acarine pests (Hao *et al*. 1996).

The Kanzawa spider mite, *Tetranychus kanzawai* Kishida, is the major acarine pest of papayas in screenhouses in Taiwan (Ho *et al*. 1997). They feed on cell chloroplasts on the under surface of the leaf, causing the upper surface of the leaf to develop a characteristic whitish or yellowish stippling, which joins and becomes brownish as mite feeding continues (Helle & Sabelis 1985; Yamada & Tsutsumi 1990; Zhang 2003). Heavy damage causes wilting and defoliation, which further reduces plant growth.

Control of *T. kanzawai* on the papaya depends mainly on chemical applications. However, the intensive application of miticides in combination with the short life cycle and high reproductive rates of mites have led to the development of resistance in the Kanzawa spider mite to many registered miticides (Cranham & Helle 1985; Goka 1998; Aiki *et al*. 2005). The number of miticides that can be used is further limited because many miticides produce unacceptable phytotoxicity to papaya (Lo 2002). Consequently, alternative measures are needed to control this papaya pest mite.

With growing concerns about environmental issues, environmentally friendly approaches have been the trend in agricultural pest management. Biological control, which utilizes carefully screened/selected natural enemies to suppress pest populations, is considered an environmentally safe method and a viable alternative to pesticides. The effectiveness of biological control is often greater in glasshouses or screenhouses than in open fields because it is easier to establish sufficient populations of natural enemy through inoculative or inundative release in an enclosed environment.

The green lacewing, *Mallada basalis* (Walker), is common in agricultural fields in Taiwan. The adults feed on nectar and honeydew, but larvae are generalist predators (Wu 1995). This lacewing is mass produced in a cost-effective manner using a microencapsulated artificial diet (Lee 2003), and is commercially available as a biological control product (authorized by Taiwan Agricultural Research Institute). In addition, cold storage techniques have been established for various life stages of this predator, which helps in shipping and scheduling releases (Wu 1992). There have been investigations suggesting its potential as a biological control agent against several species of arthropod pests, including *Phyllocnistis citrella* Stainton, *Aphis* spp., *Nipaecoccus filamentosus* (Cockerell), *Diaphorina citri* Kuwayama, and *Panonychus citri* on citrus; *A. gossypii* Glover on sweet pepper; *T. urticae* Koch and *T. kanzawai* on strawberry; and *P. citri* on Indian jujube (Lo 1997; Lu & Wang 2006). However, no field information is available for this lacewing in controlling mite pests on papayas.

Our previous laboratory studies demonstrated that all larval instars of *M. basalis* were active searchers exhibiting high prey acceptability of *T. kanzawai*, relatively short handling times and voracious consumption of all life stages of the mite (Cheng *et al*. 2009). In choice tests, *M. basalis* did not show an age-class preference for *T. kanzawai* (Cheng *et al*. 2010). A laboratory assessment showed that a predator : prey ratio of 1 : 30 significantly reduced *T. kanzawai* densities of all life stages; however, population suppression was better at higher predator-prey ratios (1 : 15 and 1 : 10) (Cheng *et al*. 2012a). A temperature study showed that *M. basalis* was capable of preying on the mites at temperatures as low as 15℃ with prey consumption increasing with temperature up to 30℃ above which rates declined (Cheng *et al*. 2012b).

Although laboratory studies showed *M. basalis* has great potential as a biological control agent against *T. kanzawai*, more field investigations are needed to evaluate its field efficacy before applying this lacewing in papaya biological control programs. This study was therefore conducted in a field setting to investigate the feasibility of using *M. basalis* to control *T. kanzawai* on papaya in a screenhouse. The objectives were to determine optimal lacewing release rates, post-release population dynamics, and efficacy in controlling mites on papaya.

MATERIALS AND METHODS

Experimental fields

The experiment was conducted in four screenhouses that were adjacent to each other at the experimental farm of Taiwan Agricultural Research Institute in Wufeng District of Taichung City, Taiwan. Treatments include a control screenhouse on the far left with lacewing egg release treatments (lowest to highest) to the right of the control. Each screenhouse was 12 m × 27 m, and consisted of 5 beds separated from each other by 0.5 m wide ditches. A total of 40 papaya plants were cultivated in each screenhouse with 8 papaya plants per bed spaced 3 m apart. Irrigation and management were standard for the region except that no insecticide or miticide was applied. The variety ‘Tainung No. 2’ was planted with seedlings about 25 cm tall on April 20, 2009. The plants were removed on August 5 as the summer investigation finished, and replanted on November 16 for the winter investigation and kept growing until February 24, 2010.

Release of green lacewings

Strips of *M. basalis* eggs obtained from our laboratory colony were used for the release treatments. The eggs were in the late stage of development, consequently, they were black in color with some individuals emerged from hatched eggs. Releases were made on papaya plants starting 3 to 4 weeks after planting when the first signs of *T. kanzawai* were observed on May 13, 2009 in the summer, and December 9, 2009 in the winter investigations, respectively, and were continued once a week for the next 8 weeks. The egg strips were stapled to the upper surface of the leaves in the middle strata of each plant with eggs in contact with the leaf surface between 15:00–16:00 hours. Each egg strip contained 100 eggs. Releases of 100-, 200-, and 300-eggs per papaya plant, plus an untreated check as a control, were implemented separately in individual screenhouses. Released egg strips were brought back to the laboratory after staying on the papaya plants for 3 days, and 10 randomly selected egg strips from each release treatment were examined for egg hatch rates. This evaluation was conducted twice, from May to July, and again from December to February to compare control efficacies between seasons.

Sampling and laboratory examination

Lacewings and mites were sampled from 12 randomly selected papaya plants from each screenhouse. Counts of all active stages of *M. basalis* found per plant stratum/leaf surface were conducted between 14:30 and 17:00 hours on the second, third, and fourth day after and one day prior to lacewing eggs releases.

T. kanzawai densities were estimated from three leaves selected from the upper, middle, and lower third of the foliage of each plant with counts coming from a piece of leaflet about 100 cm^2 in dimension covering the leaf midvein to the leaf margin. Individual leaflet samples were placed in labeled plastic bags and brought back to the laboratory for the mite counts. Mite sampling was conducted in the morning of the weekly lacewing releases, and continued 3–4 more times at the same weekly interval after the last lacewing release. Individual plants were not re-sampled within a 3-wk period, and newly produced leaves were not sampled.

All mite life stages (egg, larva, nymph, and adult) were counted in the laboratory under a microscope and recorded separately for upper versus lower leaf surfaces from upper, middle and lower plant strata. Control efficacy was computed as the number of mites in the untreated check minus the number of mites in the specific release rate treatment divided by the number of mites in the untreated check each week lacewing were released, and then averaged across all weeks of lacewing releases for summer and winter investigation, respectively.

During the investigation periods, temperatures and relative humidity in the screenhouses were monitored using an Onset HOBO data logger. Papaya plant heights were recorded once a week.

Data analyses

All data except of those for the weekly population dynamics of lacewings and mites counts were averaged across sampling dates during the summer and the winter investigation, respectively. Normally distributed data were analyzed using analysis of variance (ANOVA), and non-normally distributed data were analyzed with the Kruskal-Wallis test. Means were separated for significance using the Fisher's protected LSD procedure. For pair-wise comparisons, a *t*-test was used to analyze normally distributed data, and a Mann-Whitney test was used to analyze non-normally distributed data. The significance level was set at $P < 0.05$. All analyses were conducted using STATGRAPHICS Centurion XV, software, 2005 (Statpoint, Inc, Herndon, VA).

RESULTS

Egg hatch rates of *M. basalis* after released on papaya plants during the summer season measured 72.13% ± 1.98% on average (with a range of 58.89% ± 2.87% to 87.27% ± 2.62%), and during the winter season measured 73.11% ± 2.50% on average (with a range of 56.89% ± 4.11% to 86.43% ± 1.39%). There were no significant differences in hatch rate among the various release rates (Summer: F = 0.1, P = 0.9043; Winter: F = 0.06, P = 0.9462) (Fig. 1). The number of lacewing larvae observed on papaya plants declined by more than 85% within 3 days after egg release (Fig. 2). During the weekly investigations, less than 5 lacewing larvae per plant were found even

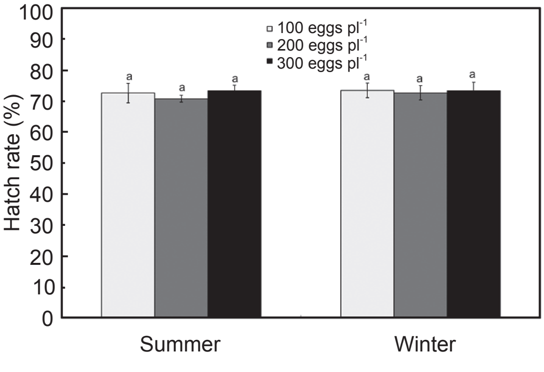

Fig. 1. Hatch rates of *Mallada basalis* eggs released on papaya plants at three rates in different seasons. Hatch rates were measured three days after egg release. Means with the same letter for each season are not significantly different at $P < 0.05$ (F-test; STATGRAPHICS Centurion XV, 2005). Error bars represent ± SEM.

with the highest release rate of 300 eggs per plant (Fig. 3). Lacewing post-release populations were lower during the winter than the summer, and the populations did not accumulate and increase through sequential releases in either season. Lacewing distributions, according to the observations, were not different either across plant strata or between upper versus lower surfaces of leaves. Even though some pupae were found during our census in the summer, no adults or second-generation eggs were observed.

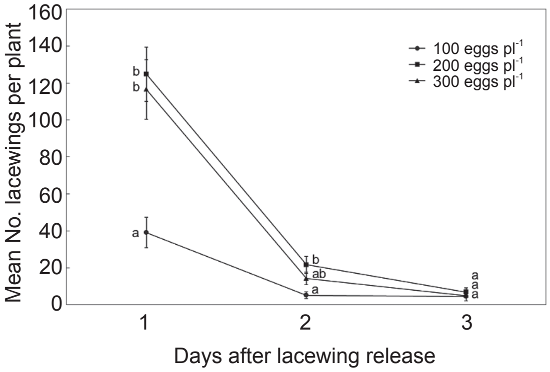

Fig. 2. Number of *Mallada basalis* observed on papaya plants within 3 days of release. Data were collected from the winter investigation, and averaged across 7 sequential release dates. Means with different letters on each date are significantly different at $P < 0.05$ (*F*-test and Fisher's protected LSD procedures; STATGRAPHICS Centurion XV, 2005). Error bars represent ± SEM.

T. kanzawai populations in the 100, 200, and 300 lacewing eggs per plant treatments were 65.7, 95.4, and 95.5% lower, respectively, compared to the control after 8 weeks of *M. basalis* egg releases in the summer (Fig. 4). *T. kanzawai* populations during the winter were near zero compared to the control after seven sequential releases, regardless of lacewing egg

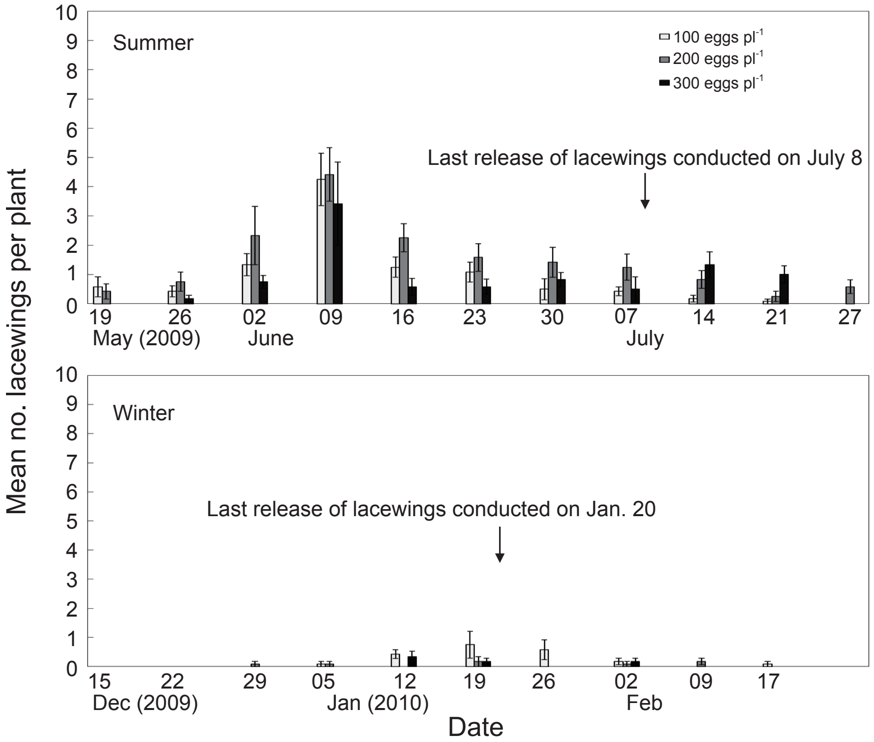

Fig. 3. Mean number of *Mallada basalis* observed per papaya plant for three different lacewing egg release rates during summer and winter. Error bars represent ± SEM. Investigations were conducted once a week on one day before each sequential release, and continued for 3–4 more weeks after the last release.

release rates (Fig. 4). After lacewing releases were completed, the mite populations increased in the screenhouses that received 200 and 300 egg release treatments, but decreased in the control and 100 egg treatments. Most papaya leaves in the control and 100 egg treatments had wilted severely from *T. kanzawai* injury at this time (pers. obs.). This was more prominent during the summer compared to the winter investigation.

T. kanzawai eggs were the most frequently observed life stage, followed by nymphs, then adults (Table 1). In the summer, most mites were distributed on the lower foliage of the papaya plant, but dispersed to the middle, then the upper strata as mite populations increased and the plants added leaves (Table 2). During the winter, similar or more mites were found on the middle plant stratum (Table 2). Almost all mites were found on the undersurface of papaya leaves (Table 3). These distribution patterns were not significantly different across the untreated check and the various rates of lacewing release treatments ($P > 0.05$, ANOVA) (Tables 1–3).

Lacewing control efficacy during the summer were not different in the treatments that received releases of 200 and 300 eggs per plant, but was significantly lower in the treatment that received releases of 100 eggs per

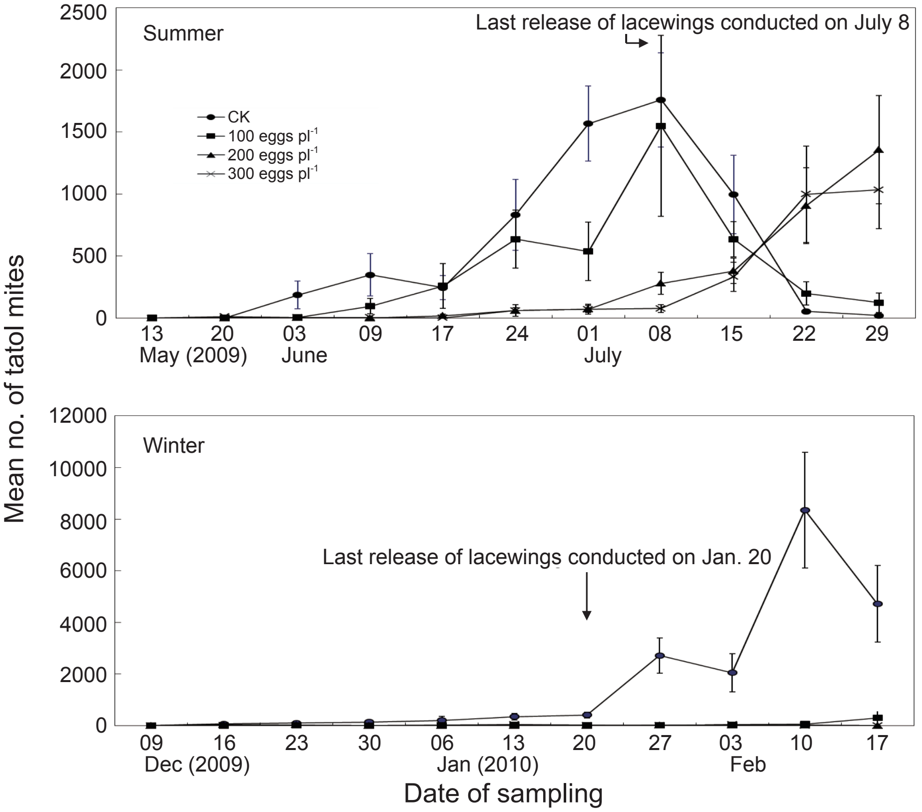

Fig. 4. Number of *Tetranychus kanzawai* observed from three leaf blade segments (approximately 100 cm^2 per leaf segment) collected respectively from the lower, middle, and upper third of papaya plants treated with different release rates of *Mallada basalis*. Error bars represent ± SEM. Sampling was conducted the same day prior to the weekly lacewing releases, and continued for 3–4 more weeks after the last release. Based on observations, most of the papaya leaves in the control and 100 egg treatments wilted severely from *T. kanzawai* injury after July 1 and February 10.

Table 1. Age class distribution of *Tetranychus kanzawai* on papaya treated with various release rates of *Mallada basalis*.

		% Mite proportion (Mean ± SE)[z]			
Investigation period	Lacewings released per plant	Egg	Larva	Nymph	Adult
Summer	100 eggs	56.3 ± 6.8 a	7.2 ± 3.4 a	23.7 ± 4.2 a	12.9 ± 4.2 a
	200 eggs	63.6 ± 2.6 a	4.6 ± 1.5 a	20.1 ± 2.5 a	11.7 ± 2.4 a
	300 eggs	63.4 ± 5.3 a	4.8 ± 2.0 a	22.3 ± 6.3 a	9.6 ± 3.5 a
	Control	60.8 ± 3.9 a	7.0 ± 1.8 a	23.5 ± 3.9 a	8.2 ± 1.1 a
Winter	100 eggs	62.4 ± 5.5 a	8.1 ± 3.0 a	18.7 ± 3.0 a	10.7 ± 2.4 a
	200 eggs	61.3 ± 5.4 a	7.2 ± 2.6 a	18.8 ± 5.0 a	12.5 ± 4.7 a
	300 eggs	62.1 ± 6.2 a	11.5 ± 2.4 a	17.2 ± 4.5 a	9.2 ± 2.7 a
	Control	72.5 ± 3.3 a	8.7 ± 2.1 a	11.5 ± 1.9 a	7.4 ± 1.1 a

[z] Means within the same column for a given season followed by the same letter are not significantly different at $P < 0.05$ (*F*-test; STATGRAPHICS Centurion XV 2005).

Table 2. Distribution of *Tetranychus kanzawai* on the lower, middle and upper third of the papaya leaf strata treated with various release rates of *Mallada basalis*.

		% Mite proportion (Mean ± SE)[z]		
Investigation period	Lacewings released per plant	Lower	Middle	Upper
Summer	100 eggs	74.3 ± 6.6 a	21.3 ± 5.4 a	4.4 ± 1.8 a
	200 eggs	74.3 ± 5.1 a	22.3 ± 5.4 a	2.2 ± 1.0 a
	300 eggs	71.7 ± 6.0 a	24.5 ± 6.4 a	3.9 ± 2.6 a
	Control	68.7 ± 4.6 a	27.5 ± 4.2 a	5.7 ± 2.2 a
Winter	100 eggs	46.8 ± 10.3 a	48.4 ± 10.2 a	4.8 ± 2.0 a
	200 eggs	34.6 ± 8.9 a	56.8 ± 8.5 a	8.7 ± 3.1 a
	300 eggs	33.4 ± 8.5 a	62.9 ± 8.3 a	3.7 ± 2.5 a
	Control	26.6 ± 7.1 a	61.8 ± 7.1 a	11.6 ± 2.1 a

[z] Means within the same column for a given season followed by the same letter are not significantly different at $P < 0.05$ (*F*-test; STATGRAPHICS Centurion XV 2005).

Table 3. Distribution of *Tetranychus kanzawai* on the upper and lower surfaces of papaya leaves treated with various release rates of *Mallada basalis*.

		% Mite proportion (Mean ± SE)[z]	
Investigation period	Lacewings released per plant	Uppersurface	Undersurface
Summer	100 eggs	2.2 ± 1.6 a	97.8 ± 1.6 a
	200 eggs	0.3 ± 0.2 a	99.7 ± 0.2 a
	300 eggs	1.3 ± 1.3 a	98.7 ± 1.3 a
	Control	1.1 ± 0.5 a	99.0 ± 0.5 a
Winter	100 eggs	2.9 ± 2.9 a	97.1 ± 2.9 a
	200 eggs	0.0 ± 2.0 a	100.0 ± 0.0 a
	300 eggs	0.0 ± 0.0 a	100.0 ± 0.0 a
	Control	0.5 ± 0.3 a	99.5 ± 0.3 a

[z] Means within the same column for a given season followed by the same letter are not significantly different at $P < 0.05$ (*F*-test; STATGRAPHICS Centurion XV 2005).

plant (Table 4). However during the winter, similar high control effectiveness (> 95%) was achieved for all three release rates (Table 4). The impact of *M. basalis* on *T. kanzawai* was similar on each life stage of the mite ($P > 0.05$, ANOVA) (Tables 1 and 4), as well as both sides of the papaya leaves ($P > 0.05$, *t*-test) (Tables 3 and 6), and throughout the canopy regardless of leaf strata (Tables 2 and 5) ($P > 0.05$, ANOVA).

During the summer, papaya heights ranged between 30–200 cm and temperatures averaged 30.5℃ (ranged 19.4–45.7℃); during the winter, papaya heights ranged between 30–80 cm and temperatures averaged 18.5℃ (ranged 5.1–40.0℃).

DISCUSSION

There have been investigations demonstrating the control effectiveness of *M. basalis* against several species of arthropod pests, including *Phyllocnistis citrella*, *Aphis* spp., *Nipaecoccus filamentosus*, *Diaphorina citri*, *T. kanzawai*, *T. urticae*, and *P. citri* in the field (Wu 1992; Chang & Huang 1995; Lo 1997;

Table 4. Mean control efficacy (± SE) of *Mallada basalis* on various mite life stages of *Tetranychus kanzawai* on papaya treated with various release rates of *M. basalis*.

Lacewings released per plant	Control efficacy (%)[z]				
	Egg	Larva	Nymph	Adult	Total mites
Summer					
100 eggs	32.0 ± 18.6 a	58.0 ± 14.5 a	58.4 ± 15.1 a	34.1 ± 15.8 a	40.5 ± 17.3 a
200 eggs	93.6 ± 2.4 a	97.5 ± 1.2 a	96.8 ± 1.2 a	96.2 ± 1.7 a	95.2 ± 1.7 b
300 eggs	95.8 ± 2.1 a	94.9 ± 3.8 a	97.2 ± 0.9 a	97.3 ± 0.9 a	96.5 ± 1.5 b
Winter					
100 eggs	94.7 ± 2.2 a	97.0 ± 1.3 a	90.4 ± 4.2 a	96.3 ± 1.4 a	95.0 ± 1.8 a
200 eggs	99.2 ± 0.3 a	98.0 ± 1.6 a	90.6 ± 8.4 a	98.1 ± 1.4 a	98.7 ± 0.6 a
300 eggs	96.8 ± 2.4 a	94.8 ± 2.6 a	93.8 ± 3.9 a	98.4 ± 1.3 a	96.5 ± 2.4 a

[z] Means within the same row for the various mite life stages followed by the same letter are not significantly different at $P < 0.05$ (*F*-test; STATGRAPHICS Centurion XV, 2005), and mean total mites within the same column for a given season followed by different letters are significantly different at $P < 0.05$ (*F*-test and Fisher's protected LSD procedures; STATGRAPHICS Centurion XV 2005).

Table 5. Mean control efficacy (± SE) of *Mallada basalis* on *Tetranychus kanzawai* on the lower, middle and upper third of the papaya leaf strata treated with various release rates of *M. basalis*.

Lacewings released per plant	Control efficacy (%)[z]		
	Lower	Middle	Upper
Summer			
100 eggs	48.7 ± 15.2 a	29.8 ± 14.4 a	70.3 ± 23.7 a
200 eggs	93.5 ± 2.3 a	98.3 ± 1.2 a	93.8 ± 4.4 a
300 eggs	94.9 ± 2.7 a	97.2 ± 1.2 a	99.9 ± 0.1 a
Winter			
100 eggs	95.2 ± 2.5 a	95.1 ± 1.7 a	92.3 ± 7.0 a
200 eggs	92.8 ± 6.1 a	99.6 ± 0.2 a	99.9 ± 0.1 a
300 eggs	91.4 ± 5.0 a	97.7 ± 1.3 a	100.0 ± 0.0 a

[z] Means within the same row followed by the same letter are not significantly different at $P < 0.05$ (*F*-test; STATGRAPHICS Centurion XV 2005).

Table 6. Mean control efficacy (± SE) of *Mallada basalis* on *Tetranychus kanzawai* on upper and lower surfaces of papaya leaves treated with various release rates of *M. basalis*.

Lacewings released per plant	Control efficacy (%)[z]	
	Uppersurface	Undersurface
Summer		
100 eggs	35.9 ± 22.1	39.9 ± 17.7
200 eggs	96.4 ± 2.2	95.1 ± 1.7
300 eggs	97.2 ± 2.8	95.6 ± 1.4
Winter		
100 eggs	100.0 ± 0.0	94.9 ± 1.8
200 eggs	100.0 ± 0.0	98.7 ± 0.6
300 eggs	100.0 ± 0.0	96.5 ± 2.4

[z] Means within the same row are not significantly different at $P < 0.05$ (*t*-test; STATGRAPHICS Centurion XV 2005).

Hao 2002; Lu & Wang 2005). However, no information is available on detailed tracking of the lacewing population after field release. The current study found that *M. basalis* egg hatch following release in a screenhouse was consistently high in both summer and winter seasons. Egg predation by ants (eggs were cut from their stalks and moved to ant nests) was observed to be the main factor affecting lacewing egg hatch; cannibalism by conspecifics played only a limited role on the hatch rate, which might explain the similarity in hatch rate among the various lacewing release rates.

M. basalis larvae from recently hatched eggs were observed actively moving throughout the papaya foliage and on leaf surfaces, petioles, stems, surrounding weeds, as well as the ground. There was no evidence that *M. basalis* preferred to inhabit or forage in specific locations on or around the plant. Larval densities declined rapidly within 3 days of egg release. Only a few lacewing larvae were found during the weekly census even for the highest release rate. Consequently, lacewing populations did not accumulate through successive releases suggesting that the mass-produced *M. basalis* were unable to grow and reproduce in the papaya screenhouses. It has long been thought that one of the reasons biological control agents fail to establish in the field is because of the impact of inter-guild predation. Rosenheim *et al*. (1999) documented that five species of generalist predators in the order Hemiptera were the potential source of *Chrysoperla carnea* mortality in the cotton field. The relatively high rates of successful hatch observed in our study suggested that it was the *M. basalis* young larvae that were vulnerable to significant predation mortality. In our papaya screenhouses, ants were the only specific predators of *M. basalis* we observed. We often observed ants moving lacewing prey and lacewings attacking their conspecifics. These two factors seemed to be the major source of predation acting on the young lacewing larvae.

Climatic conditions are also important determinant of organism survival. Chang (2000) indicated that the effective temperature for *M. basalis* development ranged from 15–43℃. The temperatures monitored in the screenhouses during our experimental periods were mostly within the upper limit during the summer, but more often dropped below the lower limit during the winter. Low temperatures during the winter might be a cause of *M. basalis* mortality, but not in the summer.

Green lacewings are generalist predators that feed on a broad array of small arthropods

(Canard & Principi 1984). Under conditions of prey scarcity, they can exploit plant-based resources, e.g., extrafloral nectar (Limburg & Rosenheim 2001). Limburg & Rosenheim (2001) indicated that extrafloral nectar did promote substantial longevity of first-instar lacewing larvae, although extrafloral nectar contributed only slightly to neonate lacewing growth and did not support lacewing development. We noticed fewer extrafloral nectaries along the leaf veins and stems of papaya plants that received lacewing release treatments compared to the untreated plants. We speculate that lacewing larvae might feed on nectaries in the screenhouse, based on direct observations under a microscope in the laboratory. Besides extrafloral nectaries, several species of *M. basalis*' natural prey occurred in our papaya screenhouses including whiteflies, larvae of tobacco cutworm, and rusty plum aphids (inhabiting goosegrass). Food limiting should not explain the sharp population drop of the first instars of *M. basalis* after successful hatch. This presumption was supported by the rapid population decline of the first instar lacewings in the 100-egg treatment screenhouse when the *T. kanzawai* population densities were high.

Generalist predator may not always respond to prey-specific cues. We observed *M. basalis* in the laboratory that searching for mite prey in a random pattern, and requiring potential prey to be within a range of a few millimeters before they are recognized by physical contact. We often found *M. basalis* in the screenhouses, not only foraging in the plant canopy, but also moving along plant stems to the ground or the surrounding weeds. Papaya has a more open canopy compared to other plants, which may be a reason lacewing larvae have a greater tendency for these movements. Moving off the plant could subject the lacewings to greater predation pressure (especially ant predation), and harsher environments including the extreme surface temperatures found on soils in the sun light. We found that *M. basalis* stayed and grew better on bitter gourd with aphid prey than on papaya with mites (pers. obs.). Whether the differences in the lacewing aggregation and development are a result of differences in attractiveness between plant species or between prey species requires further investigation.

M. basalis did not grow well in the screenhouse in this study, but did generate good control against *T. kanzawai*. Cheng *et al*. (2009) demonstrated that *M. basalis* was a voracious predator with the first-instar larva consuming an average of 20 *T. kanzawai* eggs in 2 hours. The lacewings might have attacked most of the mites in the experimental screenhouses before their population declined to low levels, or they might move out of our sight, but come back to the plant to forage at some other time.

There have been several field investigations demonstrating the effectiveness of *M. basalis* in controlling acarine pests. Chang & Huang (1995) reported that *M. basalis* released at the rate of 5 first instar larvae per plant once every 3 weeks for a total of three releases reduced *T. kanzawai* populations on strawberry by 60%. Hao (2002) indicated that *M. basalis* released at 200 eggs per plant once every 7–10 days (9 successive releases) reduced *P. citri* populations on Indian jujube in net houses by 90%. Wu (1992) demonstrated that *M. basalis* released at a rate of 1,000 eggs per tree effectively reduced *P. citri* on citrus. The current study demonstrated that *M. basalis* released at a rate of 200 eggs per plant once every week reduced *T. kanzawai* populations during the summer by 95%. Mite populations were lower during the winter and could be controlled by the lower release rate of 100 eggs per plant to achieve the same level of control observed during the summer. Cheng *et al*. (2012b) reported that consumption of *T. kanzawai* by 2nd instar *M. basalis* increased between 15 and 30℃ , and then declined between 30 and 35℃. Although lacewing predation was lower during the winter, *T. kanzawai* also has a lower population growth at lower temperatures. On the other hand, *T. kanzawai* population growth rates during the summer are optimal at 34℃ (Chang 2000), which is beyond the optimum temperature range for *M. basalis* predation. These might explain why *M. basalis* was better at controlling these mites in the winter than in the summer. However, the period of effective lacewing control after termination of releases could not be measured accurately in this study because the mites began migrating from the untreated screenhouse to the lacewing-treated screenhouses, perhaps because of food deprivation, thus interfering with the regular paces of mite population increases.

Mite eggs were the most frequently observed age class of *T. kanzawai* followed by nymphs, then adults in papaya screenhouses, which was consistent with prior knowledge (Zhang 2003). Mites were most abundant in the lower and middle vertical strata of the plant canopy and least abundant on the young leaves in the upper canopy. Furthermore, mites were found predominantly on the lower surface of leaves. When populations reached relatively high densities in the lower plant canopy, mites tended to move from the lower to the upper plant strata. Differences in predator-prey relative mobility and spatial distribution, and prey nutritional value may result in predators preferring or only being capable of attacking certain life stages of prey, or prey at specific localities. This often affects the effectiveness of biological control agents against their target pest. Our results showed that the age class distribution of *T. kanzawai* and their population distribution over different papaya plant strata and leaf surfaces for different lacewing release rate treatments and the untreated check were not significantly different. It was also shown that control efficacies were similar for various mite life stages and on papaya leaf/canopy localities. Besides, *M. basalis* were active at the various papaya localities (papaya heights within 2 m) with similar frequency. These suggest that *M. basalis* contains *T. kanzawai* of all life stages across the entire papaya plant. It corresponds to our previous findings from a laboratory study that *M. basalis* does not discriminate among various life stages of *T. kanzawai*, and suppresses mites of all life stages and on both sides of papaya leaves (Cheng *et al*. 2012a, 2012b). These are important attributes for *M. basalis* to be an effective biological control predator for papaya mite pest management.

The environmental conditions of screenhouses are easier to manipulate than those in the open field, thus should increase the success of biological control applications. There has been research suggesting that the use of lacewings is best suited to glasshouses or other enclosed systems (Daane *et al*. 1998). The current study indicated that environmental conditions in the papaya screenhouses are still not favorable for *M. basalis* development and population establishment. Nevertheless, the lacewing at the release rate of 200 eggs per plant did provide good control against papaya pest mites, and release rates could be further reduced to 100 eggs per plant for the winter application. *M. basalis* can be mass-produced on artificial diet in a cost-effective manner. With the current techniques, production of a *M. basalis* adult has been estimated being about 0.028 USD including diets, labor, utility, and facility, and one female can produce an average of 736.3 eggs per lifetime. Therefore, each release of *M. basalis* for controlling *T. kanzawai* on papaya costs about 40 USD ha^{-1}. Although our study suggested that control of *T. kanzawai* on papaya would not be achieved by inoculative releases of *M. basalis*, inundative releases as a biological pesticide should be viable.

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應用基徵草蛉 (Neuroptera: Chrysopidae) 防治網室木瓜上神澤氏葉蟎 (Acari: Tetranychidae) 之研究

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摘要

陳健忠、鄭玲蘭、董耀仁、盧秋通、吳文哲、J. S. Yaninek。2014。應用基徵草蛉 (Neuroptera: Chrysopidae) 防治網室木瓜上神澤氏葉蟎 (Acari: Tetranychidae) 之研究。台灣農業研究 63(2):91–104。

基徵草蛉 *Mallada basalis* (Walker) 屬非專一性的捕食性昆蟲，為台灣農作區常見的天敵種類，可利用人工飼料加以大量繁殖，具經濟效益並已商品化。往昔研究顯示基徵草蛉可應用於田間防治多種作物的重要害蟲及害蟎，但於網室木瓜尚無正式報告。此外，對於草蛉釋放後，其族群在田間變動的情形也少有探討。本研究乃探討網室中釋放基徵草蛉防治木瓜害蟎之可行性，主要項目包括草蛉的有效釋放率、釋放後草蛉在田間的族群變動情形、以及其對木瓜上神澤氏葉蟎 *Tetranychus kanzawai* Kishida 的防治效能。結果顯示每株木瓜釋放 200 粒草蛉卵，夏天每次釋放後的平均防治率可達 95% 以上，冬天由於葉蟎族群密度較低，草蛉釋放率可降至每株木瓜 100 粒卵，即達相同的防治效果。此外，基徵草蛉對木瓜植株上不同生活期、不同葉層或不同葉表的葉蟎，防治效果皆無顯著差異。草蛉卵釋放於木瓜網室後的孵化率達 70% 以上，然而稚齡幼蟲孵化後，其族群密度即迅速降低。草蛉在木瓜網室中無法經由連續釋放累積其族群數量，顯示木瓜網室無法提供草蛉生長發育所需的適當環境。雖然基徵草蛉無法在木瓜網室中建立族群，本研究顯示以淹沒式釋放方式 (inundative release)，在每株木瓜上視季節釋放 100–200 粒基徵草蛉卵，可有效防治木瓜上之神澤氏葉蟎，具應用潛力。

關鍵詞：神澤氏葉蟎、基徵草蛉、生物防治、淹沒式釋放、木瓜。

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