Agriculture and Natural Resources 50 (2016) 460–464

Contents lists available at ScienceDirect

Agriculture and Natural Resources

journal homepage: http://www.journals.elsevier.com/agriculture-and-natural-resources/

Original Article

Larval preference and performance of the green lacewing, *Plesiochrysa ramburi* (Schneider) (Neuroptera: Chrysopidae) on three species of cassava mealybugs (Hemiptera: Pseudococcidae)

Charida Sattayawong,* Sopon Uraichuen, Wiwat Suasa-ard

Department of Entomology, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom 73140, Thailand

ARTICLE INFO

Article history:
Received 21 January 2016
Accepted 19 July 2016
Available online 3 January 2017

Keywords:
Integrated pest management
Mass rearing
Prey suitability
Reproductive rate
Pseudococcus jackbeardsleyi

ABSTRACT

The green lacewing, *Plesiochrysa ramburi* (Schneider) (Neuroptera: Chrysopidae), is a dominant predatory insect in cassava fields. The suitability of different cassava mealybug species as prey for *Pl. ramburi* is important information for mass rearing in the laboratory. *Phenacoccus manihoti* Matile-Ferrero, *Phenacoccus madeirensis* Green and *Pseudococcus jackbeardsleyi* (Gimpel & Miller) were compared to determine their potential as prey for *Pl. ramburi* larvae by testing the green lacewing's preference and performance. Non-choice tests showed that *Pl. ramburi* larva could feed on all three cassava mealybug species. Choice tests showed that the 1st and 2nd instars of *Pl. ramburi* preferred *Ph. manihoti* and the 3rd instars preferred *Ph. madeirensis*. However, life table parameters showed that the highest net reproduction number (19.1967) and gross reproductive rate (46.0156, females/female/generation) occurred when *Pl. ramburi* fed on *Ps. jackbeardsleyi*. This indicates that *Ps. jackbeardsleyi* is the most suitable diet for the mass rearing of *Pl. ramburi* to allow releases in integrated pest management programs.

Introduction

Cassava mealybugs are important cassava insect pests, with more than 15 species of mealybugs attacking cassava in the Americas, Africa and Asia (Bellotti, 2002). The pink mealybug, *Phenacoccus manihoti* Matile-Ferrero, and the cassava mealybug, *Phenacoccus herreni* Cox & Williams, originated in the Neotropical region and are the most economically important insect pests causing severe yield reduction in cassava fields (Herren and Neuenschwander, 1991; Bellotti, 2002).

Five species of cassava mealybugs attack cassava in Thailand: pink mealybug, *Ph. manihoti*, madeira mealybug, *Phenacoccus madeirensis* Green, Jack Beardsley mealybug, *Pseudococcus jackbeardsleyi* (Gimpel & Miller), striped mealybug, *Ferrisia virgata* (Cockerell), and solenopsis mealybug, *Phenacoccus solenopsis* Tinsley. Among these, *Ph. manihoti*, *Ph. madeirensis*, and *Ps. jackbeardsleyi* are considered as the key insect pests of cassava in Thailand (Calatayud and Le Rü, 2006; Soroush et al., 2012).

Ph. manihoti originated in central South America (Neuenschwander, 2003) and was accidentally introduced into Africa in the early 1970s. It rapidly increased in numbers and dispersed across the cassava-growing regions, causing yield losses in large areas of cassava fields in Africa. In the Americas, *Ph. manihoti* was first recorded in Paraguay in 1980 and was later collected from areas of Bolivia and Mato Grosso do Sul State of Brazil but did not cause economic damage in the 1980s (Löhr et al., 1990). Meanwhile, *Ph. manihoti* was also found in Cambodia and Indonesia and caused damage to cassava there. In addition, *Ph. manihoti* has also attacked cassava in the Brazilian States of Paraná, Sao Paulo, Bahia and Pernambuco, where it seriously reduced cassava yields (Bellotti et al., 2012). In Thailand, *Ph. manihoti* was first found in 2008 and the economic loss due to *Ph. manihoti* on cassava in Thailand rapidly increased up to USD 1 million (Winotai et al., 2010).

Ph. madeirensis is distributed worldwide and attacks a wide range of plant species (Williams and Granara de Willink, 1992; Ben-Dov, 1994), being an insect pest on ornamental plants both outdoors and in greenhouses (Pellizzari and Germain, 2010) and has become an important insect pest of greenhouse ornamentals in the southeastern USA since the early 1990s (Townsend et al., 2000).

Ps. jackbeardsleyi is a polyphagous species that originated in the Neotropical region and can attack more than 93 plant species including vegetables, fruits and ornamental crops (CAB International, 2001). In Asia, *Ps. jackbeardsleyi* was first recorded in Singapore in 1958, followed by Malaysia (1969), Indonesia (1973), the Philippines (1975), Brunei (1979), Thailand (1987) and

* Corresponding author.
E-mail address: charida.tu@gmail.com (C. Sattayawong).

http://dx.doi.org/10.1016/j.anres.2016.07.002

in 1994 in the Maldives and Vietnam (Williams, 2004a,b; Muniappan et al., 2009).

Biological control is globally recommended to control cassava mealybugs in cassava plantations. Many any species of natural enemies are used for the control of cassava mealybugs, including: *Anagyrus lopezi* (De Santis), *Apoanagyrus diversicornis* (Howard), *Parapyrus manihoti* Noyes, *Allotropa* sp., *Hyperaspis notata* Mulsant, *Sympherobius maculipennis* Kimmins, *Diomus* spp. and *Exochomus* sp. (Löhr et al., 1990; Neuenschwander, 1994; Ru and Makosso, 2001). Uraichuen et al. (2011) reported that in Thailand, there are several natural enemies that are present in fields: *Plesiochrysa ramburi* (Schneider), *Mallada basalis* (Walker), *Allotropa suasaardi* Sarkar & Polaszek, *Wollastoniella rotunda* Yasunaga & Miyamoto, *Orius maxidentex* Ghauri and *Nephus ryuguus* (H. Kamiya). Among these, *Pl. ramburi* is the dominant natural enemy of cassava mealybugs.

Pl. ramburi is an important predatory insect of a number of mealybugs such as the pineapple mealybug, *Dysmicoccus brevipes* (Cockerell), citrophilus mealybug, *Pseudococcus calceolariae* (Maskell), longtailed mealybug, *Pseudococcus longispinus* (Targioni Tozzetti), and an unidentified species belonging to the genus *Pulvinaria* (Tauber et al., 2001; Miller et al., 2004). In Thailand, the mealybug prey of *Pl. ramburi* include citrus mealybug, *Nipaecoccus viridis* (Newstead) and hibiscus mealybug, *Maconellicoccus hirsutus* (Green) (Kantha et al., 2004). Recently, it has been reported as an important natural enemy of cassava mealybugs in cassava fields in Thailand (Uraichuen et al., 2011).

To produce great numbers of predators, effective mass-rearing techniques need to be developed. The quality and quantity of prey species influences the biology and behavior of the predatory lacewings (Thompson, 1951; Canard and Principi, 1984; Strohmeyer et al., 1998; Thompson and Hagen, 1999) and preference and suitability of prey for predator development are important characteristics in determining the potential of predators as biological control agents for a specific pest, as this can decide the success or failure of predators in biological control (Thompson, 1951). For example, Osman and Selman (1993) showed that *M. persicae* and *Acrthosiphon pisum* Harris were the most suitable prey for *Chrysoperla carnea* (Stephens), whereas *Aphis fabae* Scopoli was an unsuitable prey species because it caused high juvenile mortality and resulted in smaller cocoons and lower fecundity compared to *M. persicae*. Similarly, the developmental durations of immature stages of *Chrysopa pallens* (Rumber) were 23.2 d, 8.5 d and 10 d when fed on *Tetranychus urticae* Koch, *Aphis craccivora* Koch and *Uroleucon nigrotuberculatum* (Olive), respectively; however, *C. pallens* cannot develop to adults when fed on *T. urticae* (Nakamura et al., 2000).

The objectives of the current study were to evaluate the influence of prey type on the biology of *Pl. ramburi* and specifically, the prey preference of *Pl. ramburi* feeding on three species mealybug that occur as pests and the influence of food on the development of the green lacewings. Such knowledge will constitute a basis for further research on the role of *Pl. ramburi* as a predator in cassava plantations.

Materials and methods

All experiments were carried out under constant laboratory condition (25 ± 2 °C and 50 ± 5% relative humidity) at the National Biological Control Research Center, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom, Thailand during 2012–2013.

Rearing of cassava mealybug species

Three cassava mealybug species—*Ph. manihoti*, *Ph. madeirensis* and *Ps. Jackbeardsleyi*—were collected from cassava plantations in Phanom Thuan, Bo Phloi and Huai Krachao districts in Kanchanaburi province, Thailand. In the laboratory, the mealybugs were sorted and reared on Thai pumpkin fruit (*Cucurbita moschata* Duchesne). Medium-sized (approximately 1 kg and approximately 20 cm in diameter) pumpkins were used as diet for rearing the mealybugs. Each pumpkin fruit was infested with 150 adult female mealybugs with well-formed ovisacs. The egg sacs and crawlers of each mealybug species were transferred individually onto the upper surface for settling and development. The infested pumpkin fruits were kept in circular plastic boxes (22 cm in diameter, 11 cm in height) and placed on shelves. To avoid cross species contamination, all plastic boxes were covered with nylon cloth and boxes of each species were placed on separate shelves. The cultures were maintained in the dark. Then, 4 wk after initial infestation, the mealybugs were collected and used for rearing *Pl. ramburi*.

Rearing of Pl. ramburi

The initial stock culture of *Pl. ramburi* was collected from a cassava field and reared in the laboratory. Larvae were transferred to pumpkin fruit bearing mealybugs aged 20–25 d, which were placed in the circular plastic boxes and covered with nylon cloth. A mixture of honey and yeast at a ratio of 1:1 was provided as food for the *Pl. ramburi* adults. Adults usually laid eggs on the inner surfaces of the boxes or on the nylon cloth. Eggs were immediately moved to Petri dishes and kept until hatching. The newly hatched larvae were used in the following experiments.

Prey species preference

No-choice tests

No-choice tests were conducted by providing 3rd instars of each of the three mealybug species to 1st, 2nd and 3rd instars of *Pl. ramburi* (treatments). Larvae of *Pl. ramburi* were transferred to Petri dishes (9 cm in diameter and 1.5 cm in depth) individually after starvation for 24 h. Each instar of *Pl. ramburi* was provided with 30 nymphs of each mealybug species. Each treatment consisted of 20 replications. The numbers of mealybugs remaining after 6 h were counted. A generalized linear model (GLM) with a Poisson error structure and a log-link function was used to test for differences in the numbers of each prey species fed on by each instar of *Pl. ramburi*. The base model included *Ps. jackbeardsleyi* because its number was lowest.

Choice tests

The choice tests used three treatments—1st, 2nd and 3rd instar of *Pl. ramburi* (treatments). Ten 3rd-instars of each mealybug species were placed in a Petri dish that contained one *Pl. ramburi* larva. Each treatment was replicated 20 times. A filter paper (8 cm diameter) was placed on the bottom of each Petri dish and a few drops of water soaked on cotton were added for moisture. The numbers of mealybug nymphs of each species remaining after 6 h were counted. Multinomial logistic regression was used to test for differences in the numbers of each prey species fed on by each instar of *Pl. ramburi*. The base model included *Ps. jackbeardsleyi* because its number was lowest.

Prey species suitability

Development periods

Newly hatched larvae of *Pl. ramburi* were transferred into individual plastic boxes (11 cm in width, 11 cm in length and 6 cm in depth) using a size 0 linear brush. A filter paper was placed on the box bottom. Each larva was fed 3rd instars of each mealybug species daily. The experiment had 20 replications. The mean developmental period of *Pl. ramburi* that consumed each mealybug species was compared and the female longevity and fecundity were also calculated. A GLM with a Poisson error structure and a log-link function was used to test for differences in the periods of each stage of *Pl. ramburi* when fed on each of the three prey species. The base model included *Ps. jackbeardsleyi*.

Biological life table study

A life table analysis of *Pl. ramburi* was carried out using each of *Ph. manihoti*, *Ph. madeirensis* and *Ps. jackbeardsleyi* as prey. Samples of 300 newly laid eggs of *Pl. ramburi* were used in each set of the study. Larvae of *Pl. ramburi* were reared in circular plastic boxes. Emerged adults were collected daily and kept in the circular plastic boxes covered with a nylon cloth and supplied with a diet mixture of water:honey:yeast at the ratio 1:1:1. The numbers of larvae and adults that survived were determined each day, and the number of eggs laid by each adult was recorded every day until the adult died. A biological life table was constructed using a technique given by Laughlin (1965) and Jervis and Copland (1996).

Results and discussion

Prey species preference

No-choice tests

In the no-choice tests, all three mealybug species were preyed on by *Pl. ramburi* larvae (Table 1). The 1st instars of *Pl. ramburi* ate more *Ph. manihoti* (10.10) than *Ph. madeirensis* (9.85) or *Ps. jackbeardsleyi* (8.60) although the differences were not significant (GLM, $p > 0.1$). The 2nd instars ate more *Ph. manihoti* (18.10) than *Ph. madeirensis* (17.75) and *Ps. jackbeardsleyi* (16.70), but again, the differences were not significant (GLM, $p > 0.1$). The 3rd instars ate more *Ph. madeirensis* (114.90) than *Ph. manihoti* (14.80) and *Ps. jackbeardsleyi* (12.50). The numbers of *Ph. madeirensis* and *Ph. manihoti* eaten were significantly greater than those for *Ps. jackbeardsleyi* (GLM, $p < 0.05$).

In no-choice testing, Uraichuen et al. (2010) found that the larvae of *Pl. ramburi* can feed on *M. hirsutus*, *B. tabaci*, *Corcyra cephalonica* (Stainton), an unidentified species belonging to the genus *Tetranychus*, unidentified species belonging to the genus *Thrips* and eggs of *Spodoptera litura* (F.). The current results showed that *Pl. ramburi* larvae could also feed on *Ph. madeirensis*, *Ph. manihoti* and *Ps. jackbeardsleyi*. Kantha (2006) showed that the 2nd instars of *Pl. ramburi* were the most voracious when fed on *M. hirsutus*. This was consistent with the current results, in which 2nd instars of *Pl. ramburi* consumed the greatest numbers of the three cassava mealybug species. Larvae of *Pl. ramburi* could feed on all three mealybug species; thus, it could be applied to control the cassava mealybugs in the field.

Choice tests

The results of the choice tests were similar to those in the no-choice tests. The 1st instars of *Pl. ramburi* ate more *Ph. manihoti* (3.50) than *Ph. madeirensis* (3.45) and *Ps. jackbeardsleyi* (2.50). The significance of the differences was marginal between *Ps. jackbeardsleyi* and each of the other two species (multinomial logistic regression, $p < 0.1$ (Table 2). The 2nd instars ate more *Ph. manihoti* (6.55) than *Ph. madeirensis* (6.40) and *Ps. jackbeardsleyi* (5.60). The 3rd instars ate more *Ph. madeirensis* (4.60) than *Ph. manihoti* (4.45) and *Ps. jackbeardsleyi* (3.60). The differences among the species 2nd instars and 3rd instars were not significant (multinomial logistic regression, $p > 0.1$; Table 2).

The results showed that more individuals of *Ph. manihoti* and *Ph. madeirensis* were preyed on by *Pl. ramburi* than *Ps. jackbeardsleyi*. This was likely related to the body size—*Ph. manihoti* and *Ph. madeirensis* are smaller (length 0.98 and width 0.53 mm, length 1 and width 0.59 mm, respectively) than *Ps. jackbeardsleyi* (length 1.98 and width 1.23 mm), and are softer. *Pl. ramburi* has difficulty in dealing with *Ps. jackbeardsleyi* using its mandibles (Wardani et al., 2014). Uraichuen et al. (2010) reported that larvae of *Pl. ramburi* preferred to feed on *M. hirsutus* compared to *B. tabaci*, *C. cephalonica*, *Tetranychus* sp., *Thrips* spp. and eggs of *S. litura*.

Table 1
Numbers (mean ± SD) of *Phenacoccus manihoti* Matile-Ferrero, *Phenacoccus madeirensis* Green and *Pseudococcus jackbeardsleyi* (Gimpel & Miller) consumed by *Plesiochrysa ramburi* (Schneider) in no-choice testing for 6 h under laboratory conditions using a generalized linear model with a Poisson error structure and a log-link function to test the effects of species and *Ps. jackbeardsleyi* as the base model.

Instar of *Pl. ramburi*	Number of mealybugs consumed		
	Ph. manihoti	*Ph. madeirensis*	*Ps. jackbeardsleyi*
1st	$10.10 \pm 1.29^{NS\dagger}$	9.85 ± 1.75^{NS}	8.60 ± 1.14
2nd	18.10 ± 1.51^{NS}	17.75 ± 1.71^{NS}	16.70 ± 2.55
3rd	$14.80 \pm 1.32^{*}$	$14.90 \pm 1.11^{*}$	12.50 ± 0.94

†NS = $p > 0.1$; $^{*}p < 0.05$.

Table 2
Numbers (mean ± SD) of *Phenacoccus manihoti* Matile-Ferrero, *Phenacoccus madeirensis* Green and *Pseudococcus jackbeardsleyi* (Gimpel & Miller) consumed by *Plesiochrysa ramburi* (Schneider) in choice testing for 6 h under laboratory conditions using a multinomial logistic regression with *Ps. jackbeardsleyi* as the base model.

Instar of *Pl. ramburi*	Number of mealybugs consumed		
	Ph. manihoti	*Ph. madeirensis*	*Ps. jackbeardsleyi*
1st	$3.50 \pm 0.51^{\dagger,*}$	$3.45 \pm 0.51^{*}$	2.50 ± 0.51
2nd	6.55 ± 0.51^{NS}	6.40 ± 0.50^{NS}	5.60 ± 0.50
3rd	4.45 ± 0.51^{NS}	4.60 ± 0.50^{NS}	3.60 ± 0.50

†NS = $p > 0.1$; * = $p < 0.1$.

Prey species suitability

Development period

The developmental durations of *Pl. ramburi* larvae feeding on the three mealybugs species are shown in Table 3. There were no significant differences in the developmental duration of each of the developing stages when fed on the three different prey species with the one exception of the pupae where there was a significant difference between *Ph. madeirensis* and *Ps. jackbeardsleyi* ($p = 0.067$). The larval-pupal stage of *Pl. ramburi* fed on *Ph. manihoti*, *Ph. madeirensis* and *Ps. jackbeardsleyi* were 20.1 d, 20.08 d and 21.08 d, respectively. The adult longevity of each sex did not differ when fed on the three mealybug species ($p > 0.05$). The adult longevities of *Pl. ramburi* females fed on *Ph. manihoti*, *Ph. madeirensis* and *Ps. jackbeardsleyi* were 19.33 d, 18.09 d and 20.42 d, respectively, while for males fed on *Ph. manihoti*, *Ph. madeirensis* and *Ps. Jackbeardsleyi*, they were 15.50 d, 14.50 d and 17.0 d, respectively (Fig. 1).

Table 3
Developmental duration (mean days ± SD) of *Plesiochrysa ramburi* (Schneider) when fed on *Phenacoccus manihoti* Matile-Ferrero, *Phenacoccus madeirensis* Green and *Pseudococcus jackbeardsleyi* (Gimpel & Miller) under laboratory conditions using a generalized linear model with a Poisson error structure and a log-link function employed to test the effects of species and *Ps. jackbeardsleyi* was used as the base model.

Stage	Developmental duration, days ± SD		
	Ph. manihoti	*Ph. madeirensis*	*Ps. jackbeardsleyi*
1st instar	3.25 ± 0.44	3.90 ± 0.72	3.50 ± 0.51
2nd instar	3.53 ± 0.51	3.94 ± 0.73	3.37 ± 0.50
3rd instar	3.61 ± 0.50	3.36 ± 0.54	3.39 ± 0.50
Pupa	9.72 ± 1.81	$8.88 \pm 1.50^{\dagger}$	10.83 ± 2.09
Larval-pupal stages	20.10 ± 3.26	20.08 ± 3.48	21.08 ± 3.60

$^{\dagger}p < 0.1$.

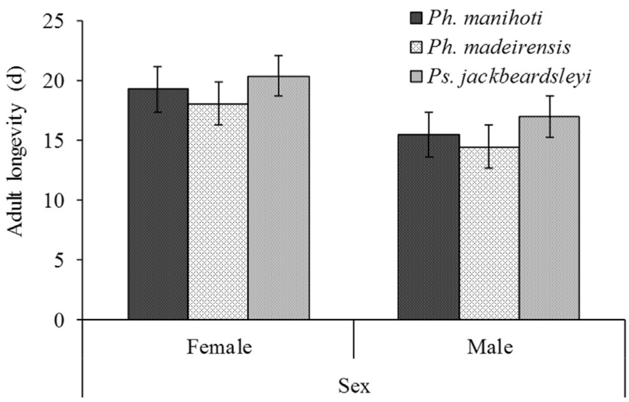

Fig. 1. Mean adult longevity of *Plesiochrysa ramburi* (Schneider) when fed on each of the three mealybug species (error bars show ± SD).

Table 4
Life table parameters of *Plesiochrysa ramburi* (Schneider) when fed on *Phenacoccus manihoti* Matile-Ferrero, *Phenacoccus madeirensis* Green and *Pseudococcus jackbeardsleyi* (Gimpel & Miller) under laboratory conditions.

Life/Fecundity table statistic	Prey species		
	Ph. manihoti	*Ph. madeirensis*	*Ps. jackbeardsleyi*
Net reproductive rate (R_0) (females/female/generation)	17.2600	17.1967	19.1967
Gross reproductive rate (*GRR*) (females/female/generation)	41.8444	40.9767	46.0156
Innate capacity for increase (r_c) (females/female/d)	0.0353	0.0350	0.0360
Intrinsic rate of natural increase (r_m) (females/female/d)	0.0545	0.0517	0.0601
Finite rate of increase (λ) (females/female/d)	1.0359	1.0357	1.0367
Cohort generation time (T_c) (d)	35.0350	35.2574	35.6418
Mean generation time (*T*) (d)	22.7092	23.8759	21.3351
Doubling time (*DT*) (d)	5.5262	5.8176	5.0050

The results showed that the developmental duration of *Pl. ramburi* was slightly different when feeding on the three mealybug species. There have been similar reports. Kantha (2006) reported that the larval stage of *Pl. ramburi* was an average 9–10 d when fed on *M. hirsutus* and *A. craccivora*. Wardani et al. (2014) demonstrated that the larval stage of *Pl. ramburi* was similar to the current observations when fed on *Ph. manihoti*. However, Choeikamhaeng et al. (2010) reported 10–14 d for the larval stage when fed on *C. cephalonica* and *Pseudococcus cryptus* Hempel.

Biological life table parameters

The life table parameters of *Pl. ramburi* feeding on *Ph. manihoti*, *Ph. madeirensis* and *Ps. jackbeardsleyi* are shown in Table 4. The greatest net reproduction number (R_0) and gross reproductive rate (*GRR*) were 19.1967 and 46.0156 (females/female/generation), respectively, on *Ps. jackbeardsleyi*. The highest innate capacity for increase (r_c), intrinsic rate of natural increase (r_m) and finite rate of increase (λ) was 0.0360, 0.0601 and 1.0367 (females/female/d), respectively, on *Ps. jackbeardsleyi*. The highest cohort generation time (T_c) was 35.6418 (d) on *Ps. jackbeardsleyi*. The shortest mean generation time (*T*) and doubling time (*DT*) was 21.3351 d and 5.0050 d, respectively, on *Ps. jackbeardsleyi*.

The high R_0 indicates that *Pl. ramburi* can be effective against the pest mealybugs. Theoretically, natural enemies that have high ability to produce offspring are proficient in controlling the population growth of their prey (Huffaker et al., 1976; Iziquel and Le Rü, 1992). Kantha (2006), who documented the parameters of *Pl. ramburi* on different prey species, showed that *M. hirsutus* was the most suitable prey for *Pl. ramburi* with an R_0 of 6.6669, which was lower than the current results. The values for r_c and λ were 0.0356 and 1.0550, respectively, which were higher than the current results. However, the T_c (35.3674) was similar to the current results. The intrinsic rate of natural increase (r_m) is one of the main criteria used for choosing the best biological control agent, as a high r_m indicates a high rate of multiplication per day of the natural enemy (Vasanthakumar and Babu, 2013). The r_m value in the current study showed that *Pl. ramburi* can multiply more when fed on *Ps. jackbeardsleyi*, which was consistent with the greatest *GRR* and the shortest doubling times of *Pl. ramburi*. Life table analysis helps to assess future offspring and estimate the number of natural enemies to be released in the biological control program (Sudhida et al., 2009). The current study showed greater reproductive parameters and shorter doubling times when *Pl. ramburi* fed on *Ps. jackbeardsleyi*, indicating that of the three mealybug species, *Ps. jackbeardsleyi* was the most suitable prey of *Pl. ramburi*.

Pl. ramburi fed on *Ph. madeirensis*, *Ph. manihoti* and *Ps. jackbeardsleyi* in the no-choice tests and showed stronger preference to *Ph. manihoti* and *Ph. madeirensis* in the choice tests. *Ps. jackbeardsleyi* was shown to be the most suitable for mass rearing *Pl. ramburi* in the laboratory (25 ± 2 °C and 50 ± 5% relative humidity), whilst *Ph. manihoti* and *Ph. madeirensis* can also be used as a substitute diet. *Pl. ramburi* showed great promise as a natural enemy to control the cassava mealybug complex in cassava fields.

Conflict of interest

There is no conflict of interest.

Acknowledgements

This research was financially supported by the Graduate School, Kasetsart University, (200,000 baht) Bangkok, Thailand and the National Biological Control Research Center (NBCRC). Colleagues at NBCRC, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom, Thailand assisted during the laboratory experiments.

References

Bellotti, A.C., 2002. Arthropod pests. In: Hillocks, R.J., Thresh, J.M., Bellotti, A.C. (Eds.), Cassava: Biology, Production and Utilization. CABI Publishing, Wallingford, UK, pp. 209–235.
Bellotti, A.C., Herrera Campo, B.A., Hyman, G., 2012. Cassava production and pest management: present and potential threats in a changing environment. Trop. Plant. Biol. 5, 39–72.
Ben-Dov, Y., 1994. A Systematic Catalogue of the Mealybugs of the World (Insecta: Homoptera: Coccoidea: Pseudococcidae and Putoidae) with Data on Geographical Distribution, Host Plants, Biology and Economic Importance. Intercept Ltd, Andover, UK.
CAB International, 2001. Crop Protection Compendium. (e-book). CAB International, Wallingford, UK. http://www.cabi.org/cpc (20 June 2014).
Calatayud, P.A., Le Rü, B., 2006. Cassava-mealybug Interactions. Institut de recherché pour le développement, Paris, France.
Canard, M., Principi, M.M., 1984. Life histories and behavior. In: Canard, M., Séméria, Y., New, T.R. (Eds.), Biology of Chrysopidae. Dr. W. Junk Publishers, The Hague, The Netherlands, pp. 57–92.
Choeikamhaeng, P., Waijirean, R., Winotai, A., 2010. Laboratory Test on the Efficiency of the Green Lacewing *Mallada Basalis* and *Plesiochrysa Ramburi* for Control Insect Pests. Bangkok, Thailand. http://www.doa.go.th/doaresearch/files/1617_2553.pdf (20 June 2014) [in Thai].
Herren, H.R., Neuenschwander, P., 1991. Biological control of cassava pests in Africa. Annu. Rev. Entomol. 36, 257–283.
Huffaker, C.B., Simmonds, F.J., Laing, J.E., 1976. The theoretical and empirical basis of biological control. In: Huffaker, C.B., Messenger, P.S. (Eds.), Theory and Practice of Biological Control. Academic Press, New York, NY, USA, pp. 41–78.
Iziquel, Y., Le Rü, B., 1992. Fecundity, longevity, and intrinsic natural rate of increase of *Epidinocarsis lopezi* (De Santis) (Hymenoptera: Encyrtidae). Can. Entomol. 124, 1115–1121.

Jervis, M.A., Copland, M.J.W., 1996. The life cycle. In: Jervis, M.A., Kidd, N. (Eds.), Insect Natural Enemies: Practical Approaches to Their Study and Evaluation. Chapman & Hall, London, UK, pp. 63–161.
Kantha, D., 2006. Biology and Utilization of *Plesiochrysa Ramburi* (Schneider) (Neuroptera: Chrysopidae) for Pest Biological Control. M.S. Thesis. Faculty of Agriculture Kasetsart University, Bangkok, Thailand (in Thai).
Kantha, D., Uraichuen, S., Chareonsom, K., 2004. Biological study and consumption of *Plesiochrysa ramburi* (Schneider) (Neuroptera: Chrysopidae). In: Proceedings of the 29th Kasetsart University Annual Conference: Plant. Kasetsart University, Bangkok, Thailand, pp. 79–85 (in Thai).
Laughlin, R., 1965. Capacity for increase: a useful population statistic. J. Anim. Ecol. 34, 77–91.
Ru, B., Makosso, J.P.M., 2001. Prey habitat location by the cassava mealybug predator *Exochomus flaviventris*: olfactory responses to odor of plant, mealybug, plant–mealybug complex, and plant–mealybug–natural enemy complex. J. Insect. Behav. 14, 557–572.
Löhr, B., Verela, A.M., Santos, B., 1990. Exploration for natural enemies of the cassava mealybug, *Phenacoccus manihoti* (Homoptera: Pseudococcidae), in South America for the biological control of this introduced pest in Africa. Bull. Entomol. Res. 80, 417–426.
Miller, G.L., Oswald, J.D., Miller, D.R., 2004. Lacewings and scale insects: a review of predator/prey associations between the Neuropterida and Coccoidae (Insecta: Neuroptera, Raphidoptera, Hemiptera). Ann. Entomol. Soc. Am. 97, 1103–1125.
Muniappan, R., Shepard, B.M., Watson, G.W., Carner, G.R., Rauf, A., Sartiami, D., Hidayat, P., Afun, J.C.K., et al., 2009. New records of invasive insects (Hemiptera: Sternorrhyncha) in Southeast Asia and West Africa. J. Agric. Urban Entomol. 26, 167–174.
Nakamura, M., Nemoto, H., Amano, H., 2000. Ovipositional characteristics of lacewings, *Chrysoperla carnea* (Stephans) and *Chrysopa pallens* (Rambur) (Neuroptera: Chrysopidae) in field. Jpn. J. Appl. Entomol. 44, 17–26.
Neuenschwander, P., 1994. Control of the cassava mealybug in Africa: Lessons from a biological control project. Afr. Crop Sci. J. 2, 369–383.
Neuenschwander, P., 2003. Biological control of cassava and mango mealybugs in Africa. In: Neuenschwander, P., Borgemeister, C., Langewald, J. (Eds.), Biological Control in IPM Systems in Africa. CABI Publ., Wallingford, UK, pp. 45–59.
Osman, M.Z., Selman, B.J., 1993. Suitability of different aphid species to the predator *Chrysoperla carnea* Stephens (Neuroptera: Chrysopidae). Univ. J. Zool. Rajshahi Univ. 12, 101–105.
Pellizzari, G., Germain, J.F., 2010. Scales (Hemiptera, Superfamily Coccoidea). BioRisk 4, 475–510.
Soroush, P., Kondo, T., Winotai, A., 2012. The cassava mealybug (*Phenacoccus manihoti*) in Asia: first records, potential, distribution, and an identification key. PLoS ONE 7 (10), e47675. http://dx.doi.org/10.1371/journal.pone.0047675.
Strohmeyer, H.H., Stamp, N.E., Jarzomski, C.M., Bowers, M.D., 1998. Prey species and prey diet affect growth of invertebrate predators. Ecol. Entomol. 23, 68–79.
Sudhida, G., Singh, A.K., Gautam, R.D., 2009. Comparative life table analysis of chrysopids reared on *Phenacoccus solenopsis* Tinsley in laboratory. J. Biol. Control 23, 393–402.
Tauber, C.A., Tauber, M.J., Albuquerque, G.S., 2001. *Plesiochrysa brasiliensis* (Neuroptera: Chrysopidae): Larval stages, biology and taxonomic relationships. Ann. Entomol. Soc. Am. 94, 858–865.
Thompson, W.R., 1951. The specificity of host relations in predacious insects. Can. Entomol. 83, 262–269.
Thompson, S.N., Hagen, K.S., 1999. Nutrition of entomophagous insects and other arthropods. In: Bellows, T.S., Fisher, T.W. (Eds.), Handbook of Biological Control. Academic Press, New York, NY, USA, pp. 594–638.
Townsend, M.L., Oetting, R.D., Chong, J.H., 2000. Management of the mealybug *Phenacoccus madeirensis*. Proc. South. Nurs. Assoc. Res. Conf. 45, 162–166.
Uraichuen, S., Sattayawong, C., Sapmok, R., Tunkhumthong, S., Kriwijit, S., Suesa-ard, W., 2010. Annual Research Report 2010 National Biological Control Research Center Feb. 2009 (in Thai).
Uraichuen, S., Tunkhumthong, S., Sapmok, R., Sattayawong, C., Chareonsom, K., Suesa-ard, W., 2011. Utilization of natural enemies for control of *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae). In: Proceedings of National Biological Control Research Center Annual Report 2011. National Biological Control Research Center. Bangkok, Thailand, p. 29, (in Thai).
Vasanthakumar, D., Babu, A., 2013. Life table and efficacy of *Mallada desjardinsi* (Chrysopidae: Neuroptera), an important predator of tea red spider mite, *Oligonychus coffeae* (Acari: Tetranychidae). Exp. Appl. Acarol. 61, 43–52.
Wardani, N., Rauf, A., Winasa, I.W., Santoso, S., 2014. The role of *Plesiochrysa ramburi* (Schneider) (Neuroptera: Chrysopidae), to control *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae) at [*sic*] cassava in West Java, Indonesia. IJSBAR 15, 343–354.
Williams, D.J., 2004a. A synopsis of the subterranean mealybug genus *Neochavesia* Williams and Granara de Willink (Hemiptera: Pseudococcidae: Rhizoecinae). J. Nat. Hist. 38, 2883–2899.
Williams, D.J., 2004b. Mealybugs of Southern Asia. The Natural History Museum, Kuala Lumpur, Malaysia.
Williams, D.J., Granara de Willink, M.C., 1992. Mealybugs of Central and South America. CAB International, London, UK.
Winotai, A., Goergen, G., Tamo, M., Neuenschwander, P., 2010. Cassava mealybug has reached Asia. Biocontrol News Inf. 31, 10N–11N.