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Evaluation of Parasitism Capacity of *Megastigmus thitipornae* Doğănlar & Hassan (Hymenoptera: Torymidae), the Local Parasitoid of Eucalyptus Gall Wasp, *Leptocybe invasa* Fisher & La Salle (Hymenoptera: Eulophidae)

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ABSTRACT

Megastigmus thitipornae Doğănlar & Hassan is the local parasitoid of *Leptocybe invasa* Fisher & La Salle, which is a devastating pest of *Eucalyptus camaldulensis* Dehn. in Thailand. This research aimed to evaluate the parasitism capacity of *M. thitipornae*. The experiments were undertaken in the laboratory and the greenhouse. The results from feeding adult *M. thitipornae* with six different diets (nine replications per treatment and ten parasitoids per replication) in the laboratory showed that diets had highly significant effects on the means of longevity of female and male parasitoids ($P < 0.01$, $P < 0.01$, respectively). A honey solution diet could extend the mean longevity of females to 9.83 ± 0.60 d (mean ± SE) and that of males to 7.83 ± 0.48 d. Estimated 50% female and male survival periods, when fed with the honey solution diet, were 8 and 4 d, respectively. The average potential fecundity (egg load) of females was 2.98 ± 0.11 eggs per female. The average female size (hind tibia length) was 0.31 ± 0.002 mm. In the greenhouse, the mean realized fecundity of females was 13.20 ± 1.95 progeny per female. *M. thitipornae* was identified as a synovigenic species. The progeny of this parasitoid had a male-biased sex ratio. *M. thitipornae* parasitized on the mature larva and pupa of the host. The single egg of this parasitoid developed as a solitary ectoparasitoid and completed its development outside the host body. The mean developmental time of *M. thitipornae* from the egg to the adult stage was 17 ± 0.44 d. When the above biological parameters of *M. thitipornae* were evaluated with those of *L. invasa* from a previous study, the results indicated that *M. thitipornae* had less parasitism capacity to control eucalyptus gall wasp (*L. invasa*) in Thailand.

Keywords: parasitism capacity, *Megastigmus thitipornae*, parasitoid, eucalyptus gall wasp, *Leptocybe invasa*, Hymenoptera, Thailand

INTRODUCTION

Eucalyptus camaldulensis Dehn. is widely planted in Thailand because it is fast-growing and is a multipurpose and economically important tree (Laemsak, 2007). *Leptocybe invasa* Fisher & La Salle is a devastating pest of this tree species. This pest is an exotic and invasive gall wasp and was first observed in *E. camaldulensis* plantations during 2004–2005. Subsequently, this pest has spread to other plantations in different parts of the country.

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The eucalyptus gall wasp, *L. invasa*, damages the newly developed leaves and young twigs of juvenile shoots of *E. camaldulensis*. This gall wasp induces numerous galls on leaf petioles, midribs and young twigs, resulting in deformity of the leaf shape, abnormality of tree growth, reduction of wood yield and a subsequent decrease in owners' incomes (Mendel *et al.,* 2004). Most *E. camaldulensis* plantations in Thailand use only some clones and these are planted in a monocultural system. Recently, attacks by this gall wasp were found to have spread from the traditional clone to the new clones of *E. camaldulensis*.

Researchers in some private sectors of Thailand have carried out *E. camaldulensis* improvement programs to produce new clones with high wood yield and gall wasp tolerance (Aramsri, 1999). However, there are still some difficulties to be solved, such as the production system of the new clones and the adaptation ability of *L. invasa* to attack the new clones. In some Mediterranean countries, researchers have used imported and local parasitoids to control this eucalyptus gall wasp (Kim *et al*., 2008; Protosov *et al*., 2008). It was noticed that the degree of success in the biological control of *L. invasa* required biological knowledge of both *L. invasa* and the parasitoids.

Recently Sangtongpraow *et al*. (2011) reported the details of the longevity, fecundity and development of *L. invasa* in western Thailand. The first author of that study also discovered *Megastigmus thitipornae*, which is the local parasitoid of *L. invasa*, in *E. camaldulensis* plantations in this part of the country. This parasitoid is a new species in Thailand (Doğănlar and Hassan, 2010). Thus, the current research aimed to evaluate the parasitism capacity of *M. thitipornae*, the local parasitoid of *L. invasa*. The parameters which were used in this study covered the longevity, fecundity and development of this parasitoid. These parameters are the key requirements for successful biological control of the gall wasp (Grabenweger *et al*., 2009).

The results obtained from this research allow comparison with those of *L. invasa* reported by Sangtongpraow *et al*. (2011). If *M. thitipornae* has better biological parameters than those of *L. invasa*, this parasitoid would have parasitism capacity to control *L. invasa* in plantations. The results would also be beneficial to decision making in the mass rearing of *M. thitipornae*.

MATERIALS AND METHODS

Mature galled *E. camaldulensis* (CT 76 clone) leaves were collected at a height above the ground of approximately 2 m by random sampling from sample plots in plantations in western Thailand. The mature galls were removed from the leaves and were kept in plastic boxes with small, moistened cotton balls inside. The boxes were maintained in the laboratory under a temperature regime of 26–32 °C. *M. thitipornae* that emerged from the galls were used in this research. The morphology and gender of the emerging parasitoids were described by viewing under a stereoscope and photographs were taken.

Longevity and survival pattern assessment

Longevity is usually expressed as the period of the parasitoid from adult to expiration. The survival pattern was denoted by the percentage of survivors each day within the range of longevity when fed with a diet. Adult *M. thitipornae* (aged less than 6 hr after emergence) were sampled from leaf galls. Large parasitoids were separated into females and males and individuals of each gender of a similar size and having great vigor were used in this study. The longevity of each sex of *M. thitipornae* was assessed by feeding with six diets—namely, no diet, pure water, pure water plus fresh flowers of *E. camaldulensis*, honey solution (honey:water = 1:1), honey solution plus fresh flowers and only fresh flowers of *E. camaldulensis*. The pure water and honey solution diets used in this study were fed by dropping onto small cotton balls.

Each of the six treatments was comprised of nine replications and ten parasitoids per replication. The experiments were conducted in small glass vials and each was covered with fine mesh to provide ventilation. All experiments were carried out in the laboratory under a temperature regime of 26–32 °C. The numbers of dead and living parasitoids in each treatment were counted daily. The longevity and survival pattern of the parasitoids on each diet were determined. The longevity of *M. thitipornae* was analysed via an F-test, using a statistical software program. Tukey's honestly significant difference test was used to compare between treatment means. A difference of means was considered significant at a level of $P < 0.05$.

Determination of fecundity

Potential fecundity

This term refers to the maximum number of mature eggs in the ovary that can potentially be laid by an adult female parasitoid at the time of investigation. The eggs can be counted directly in the ovary of the adult by dissection. To determine potential fecundity (egg load), the newly emerging *M. thitipornae* (not older than 12 hr) from leaf-galls were used in this study. The parasitoids were kept in small glass vials each covered with fine mesh. Honey solution was fed to them by dropping it onto small cotton balls in the vials.

The female parasitoids were placed in seven vials with ten parasitoids per vial. The females were killed at ages 12 hr, and 1, 2, 3, 4, 5 and 6 d by freezing. Their ovaries were dissected in saline solution under a stereoscope. The number of mature eggs in each female was determined. The effect of age on the mean egg load was analyzed via an F-test. For the next experiment, the number of mature eggs in each female parasitoid (n = 75) was counted. The length of the hind tibiae of females of all ages were measured. The hind tibia length was used as a substitute for female size (Jervis, 2005). The relationship between the number of mature eggs (egg load) and size (hind tibia length) was analyzed via simple linear regression, using a statistical software program.

Realized fecundity

This term denotes the total number of mature eggs actually laid over the lifetime of a parasitoid. Generally, it is determined by counting the real number of eggs disposed daily on a host until the female dies and by then calculating the total number of eggs laid on the host over the lifetime of a female. In the case of *L. invasa*, the difficulty is that the eggs of this host are in the leaf-galls of *E. camaldulensis*. Consequently, the eggs laid daily on the host by *M. thitipornae* are difficult to detect. This research determined the realized fecundity of *M. thitipornae* by counting the total number of emerging progeny (or the emerging adult offspring) over the lifetime of the female parasitoid and expressing it in terms of progeny per female. The study of realized fecundity was divided into two parts as described below.

Part 1—determination of the appropriate gall stage for parasitism of the parasitoid: The eucalypt plants were planted in pots, so that the shoots were kept fresh throughout the experiment. Twenty shoots of *E. camaldulensis* were sampled. Each shoot was enveloped with fine mesh and, the adult *L. invasa* females (aged less than 6 hr after emergence) were released inside the envelope for 24 hr, using five females per shoot. The leaf galls were allowed to develop. The development of *L. invasa* in the leaf galls was divided into four stages (egg, young larva, mature larva and pupa) and five shoots were used in each stage.

When the development of *L. invasa* reached each stage, one pair of *M. thitipornae* (female and male; aged 2 d), which were fed with honey solution prior to use, were introduced to each infested shoot inside the envelope for 24 hr. After exposure, the fine mesh was removed from the shoot. Before the emergence of *L. invasa* and parasitoids (12 d, which had been determined from the study on development), the galled leaves of each shoot were enveloped with fine mesh again. The number of emerging wasps from the galled leaves was determined. The appropriate gall stage for parasitism of *M. thitipornae* was assessed. The experiments were carried out in a ventilated greenhouse under a temperature regime of 26–33 °C.

Part 2—assessment of realized fecundity of the parasitoid: Two hundred shoots of *E. camaldulensis* were sampled from the plants in pots. Each shoot was wrapped with fine mesh which was tied to the lower part of the branch to make an envelope surrounding the shoot. The adult *L. invasa* females (aged less than 6 hr after emergence) were released inside the envelope for 24 hr, using five females per shoot. After exposure to *L. invasa*, the leaf galls were allowed to develop to various stages. At the time of each appropriate gall stage for parasitism, one pair of *M. thitipornae* (female and male; aged 2 d), which were fed with honey solution prior to use, were introduced to each infested shoot for 24 hr. On the next day, the pair of parasitoids were transferred to a new infested shoot. The shoot was shaken until the pair of parasitoids flew to perch in the inner envelope, the lower part of the envelope was then untied and moved to enwrap the new shoot, the lower part of the envelope was tied to a small branch of the new shoot and each pair was then left for 24 hr. This regime was conducted daily until all the parasitoids had died. This experiment ran for 20 d using 10 shoots per day, so 200 shoots were used.

During the experiments, the parasitoids were fed with the honey solution on small cotton balls hanging on the shoots. The studies were conducted in a ventilated greenhouse covered with fine mesh. Before the emergence of the *L. invasa* and the parasitoids, the galled leaves of each shoot were enveloped with fine mesh again. The numbers of emerging *L. invasa* and of the parasitoids were counted. The realized fecundities of *M. thitipornae* and the sex ratio were assessed.

Study on development of *M. thitipornae*

The development of *M. thitipornae* ranged from the egg to the adult stage. The egg stage was initiated after the female *M. thitipornae* was introduced to an infested shoot caused by *L. invasa*. Oviposition behaviors of the parasitoid were observed closely and photographs were taken. Parasitism of *M. thitipornae* in different stages of development of *L. invasa* was investigated.

From plant preparation, 10 plants were randomly selected and were used in the developmental study of parasitoids. Each plant shoot was enveloped with fine mesh, exposed to five female *L. invasa* which were then left inside the fine mesh for 24 hr. The females of *L. invasa* used in this experiment were aged less than 6 hr post-emergence and were fed with honey solution prior to use. After exposure to *L. invasa,* the leaf galls were allowed to develop to various stages. Two pairs of parasitoids (aged 2 d) which were fed with honey solution prior to use were introduced for 24 hr to each infested shoot at the appropriate gall stage. The study was conducted in a ventilated greenhouse covered with fine mesh.

After exposure, the fine mesh was removed from each shoot. Five leaves were collected at 2 d intervals. The galls were removed from the leaves and were dissected every 2 d until the emergence of all parasitoids was completed. The fresh larvae and pupae of the parasitoids were studied and photographed. The development of *M. thitipornae* was determined.

RESULTS AND DISCUSSION

Female and male *M. thitipornae* from the study are shown in Figure 1. The female *M. thitipornae* differs from the male by: the shape of stigma on the forewing, the number of adnotaular seta at the midlobe of the mesoscutum, the body color and the ovipositor. The last two characters could be used to separate female and male *M. thitipornae* in the field.

The shape of stigma on the forewing was a narrow small oval in the female and a large oval in male. There were two pairs of adnotaular seta at the midlobe of the mesoscutum in the female and four pairs in the male; the body color was brownish yellow in the female and yellow in the male.

Longevity and survival pattern

In the laboratory, the results from feeding adult *M. thitipornae* (aged less than 6 hr after emergence) with six different diets (9 replications per treatment and 10 parasitoids per replication) showed that diets had highly significant effects on the mean longevity of female parasitoids (F = 170.294, degrees of freedom = df = 5, $P < 0.01$) and male parasitoid (F = 128.491, df = 5, $P < 0.01$). The experimental details are shown in Table 1. Feeding honey solution and honey solution + flowers of *E. camaldulensis* to *M. thitipornae* parasitoids prolonged the mean longevity of females to 9.83 ± 0.60 and 9.17 ± 0.48 d and of males to 7.83 ± 0.48 and 8.00 ± 1.58 d, respectively. These two diets could extend longevities of this parasitoid to a greater extent than the other diets which maintained longevity for only approximately 1 d.

As the longevity of *M. thitipornae* parasitoids which were fed with honey solution and honey solution + flowers were not significantly different, the prolongation of the longevity of female and male *M. thitipornae* in the laboratory by feeding with honey solution only was more practical and convenient.

The survival patterns of adult female and male *M. thitipornae* were divided into two groups. The parasitoids that were fed with honey solution and honey solution + flowers had very

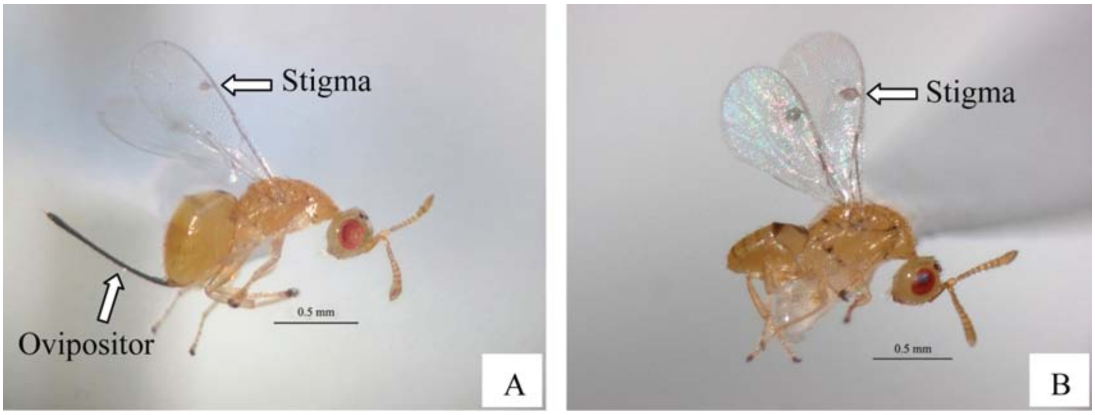

Figure 1 *Megastigmus thitipornae*: (A) Female; (B) Male.

Table 1 Longevity of female and male *Megastigmus thitipornae* fed with six different diets.

Diet	Longevity (days)	
	Female	Male
No diet	1.00±0.00[a]	1.00±0.00[a]
Water	1.17±0.17[a]	1.00±0.00[a]
Water + flowers	1.33±0.21[a]	1.17±0.17[a]
Honey solution	9.83±0.60[b]	7.83±0.48[b]
Honey solution + flowers	9.17±0.48[b]	8.00±1.58[b]
Flowers	1.00±0.00[a]	1.00±0.00[a]

Values are shown as mean ± SE; Female: $F = 170.294$, df = 5, $P < 0.01$; Male: $F = 128.491$, Degrees of freedom = 5, $P < 0.01$.

Means followed by the same superscript letter within each column are not significantly different (Tukey's honestly significant difference test, $P < 0.05$).

long survival periods, ranging from 1 to 13 d and 1 to 12 d for females, and 1 to 10 d and 1 to 11 d for males, respectively. It was estimated that the 50% survival rate periods of females and males, when fed with honey solution only, were 8 and 4 d, respectively (Figure 2). When fed with the other four diets, the estimated 50% survival rate periods of the females and the males were very short—less than 3 d. Extending the longevity and survival pattern of *M. thitipornae* by a honey solution diet will be useful for mass rearing of this parasitoid in the laboratory.

It was possible that the longevity of adult females of *M. thitipornae* in eucalypt plantations was approximately 1 d after emergence without a honey diet from flowering plants, and was approximately 9 d with a honey diet from such sources. A similar tendency was found in adult males with approximately 8 d with a honey diet from flowering plants in the plantation.

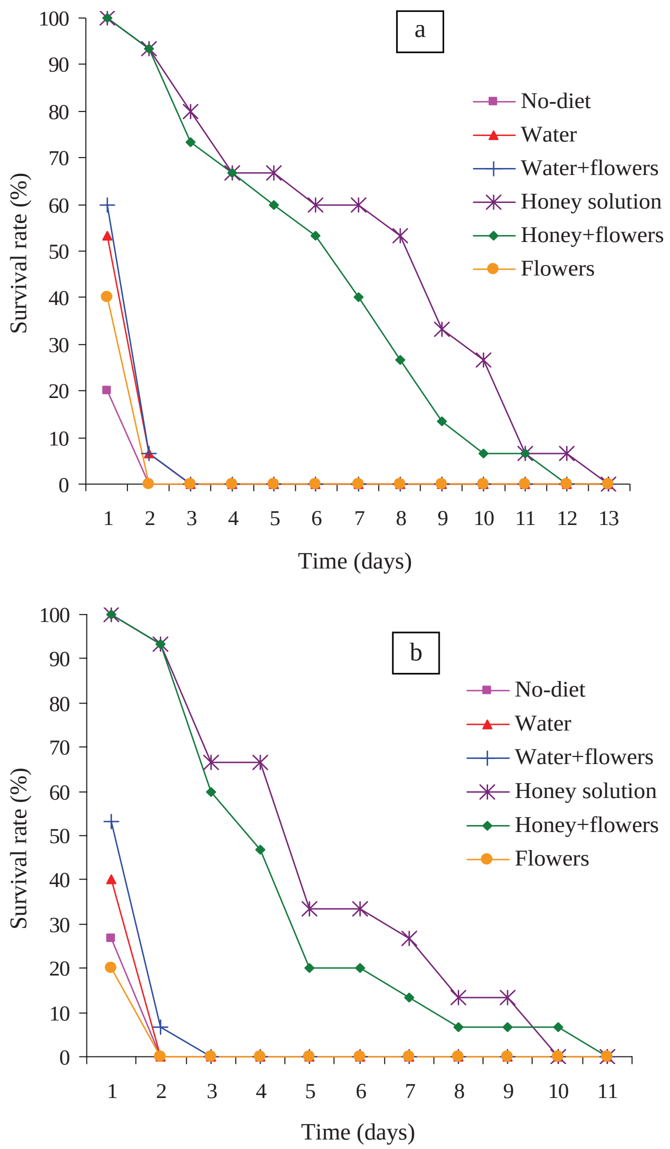

Figure 2 Survival patterns of *Megastigmus thitipornae* fed with six different diets: (a) Female; (b) Male.

The findings on the longevity of female and male *M. thitipornae* from this study were in line with those from Protasov *et al.* (2008), who studied the longevity of female and male *Megastigmus* sp.-I, the local parasitoid in Israel. They fed the parasitoids with eight different diets and found that a honey solution could clearly extend the mean longevity of *Megastigmus* sp.-I.

In principle, the longevity of a parasitoid should be greater than that of its host. The longer a male parasitoid can live, the more female parasitoids he can inseminate, and, therefore, the more eggs can be fertilized. On the other hand, the longer a female parasitoid can live, the more eggs she can lay. So the population of parasitoids would increase faster than that of its host (Jervis, 2005; Grabenweger *et al*., 2009).

Fecundity

Potential fecundity

In the laboratory, the results from the dissection of ovaries of female *M. thitipornae* showed that all eggs in a pair of ovaries of newly emerging females (aged 12 hr) were immature. Some were mature when the females were aged 2 d after emergence. The average potential fecundity (egg load) of the females, of all ages, was 2.98 ± 0.11 eggs per female, ranging from 1 to 5 eggs per female. Using the hind tibia length as a substitute for female size, it was found that the average female size (hind tibia length), of all ages of *M. thitipornae*, was 0.31 ± 0.002 mm, ranging from 0.25 to 0.36 mm.

The potential fecundity of *Megastigmus* might vary with the species and the environmental conditions. Bouaziz and Roques (2006) studied the potential fecundity of the chalcid wasp, *Megastigmus wachtli* Seither (a seed eater of cypress), and found that their eggs in ovaries were mature when the females were aged 12 d after emergence. The average potential fecundity of the female *M. wachtli* was 7.80 ± 6.40 eggs per female.

Usually, the width or length of some body parts of Hymenopteran parasitoids, such as the head, thorax and hind tibia, have been used to represent the body size (Jervis, 2005). Thus, the hind tibia length of *M. thitipornae* could be used as a substitute for female size in this study of potential fecundity.

The relationship between egg load (number of mature eggs) and female size (hind tibia length) was analyzed via simple linear regression. The results showed that there was a positive relationship between the egg load (y) and size (x) ($y = 15.704x – 1.784$, coefficient of regression = $R^2 = 0.156$, $n = 75$, $P < 0.01$). The *P* value showed that the model was acceptable at this level of significance. The larger-sized females tended to produce more eggs than the smaller-sized females. The coefficient of regression indicated that the size influenced the egg loads only about 15.6%. Thus, in addition to size, there were other variables which might be involved and influence the egg load of *M. thitipornae* (Figure 3).

The effect of female age (days after exclusion) on the mean egg load of *M. thitipornae* is shown in Figure 4. One-way analysis of variance showed that age had no significant effect on the mean egg load of this parasitoid ($F = 0.308$, df = 4, $P > 0.05$). This finding from this research was consistent with Bernado *et al*. (2005), who studied the potential fecundity of *Tripobias semiluteus* Bouček (Hymenoptera: Eulophidae).

Realized fecundity

In the ventilated greenhouse, all eggs in ovaries of newly emerging female (aged 12 hr) of *M. thitipornae* were immature. Some eggs were mature when the females were aged 2 d after emergence. Oviposition was also underway on the second day after their emergence, then it gradually increased and was at its maximum on the fourth day with 2.87 ± 0.55 progeny per female; then it gradually declined and lasted until the tenth day (Figure 5). The mean realized fecundity of females, from the second day to the tenth day, was 13.20 ± 1.95 progeny per female, ranging from 5 to 30 progeny per female.

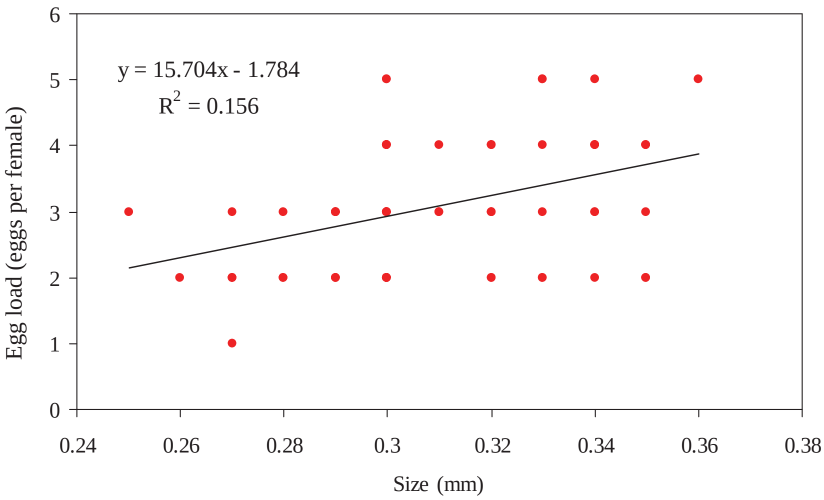

Figure 3 Relationship between predicted egg load (y) and size (x) of *Megastigmus thitipornae*. The straight line regression equation of egg load on size is y = 15.704x – 1.784 (Coefficient of regression = R^2 = 0.156, n = 75, P < 0.01).

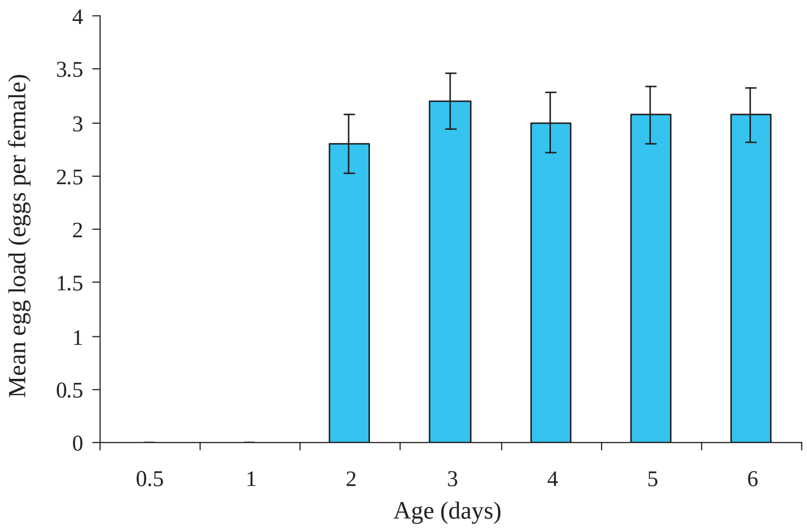

Figure 4 Effect of age on mean egg load of *Megastigmus thitipornae* (F = 0.308; Degrees of freedom = 4; P > 0.05). The vertical bars indicate standard error.

The realized fecundity pattern of *M. thitipornae*, as shown in Figure 5, indicates that this species is a synovigenic species. This was characterized by: all eggs in the ovaries of newly emerging adults being immature, the adults ovipositing on the first or second day after emergence, the mean progeny per female gradually increasing and reaching its maximum near the middle of adult-life and then gradually declining, and the mean realized fecundity being higher than the mean potential fecundity. These characters of a synovigenic species were defined by Gordh *et al*. (1999) and Jervis *et al*. (2001). Usually, a synovigenic parasitoid is more effective in

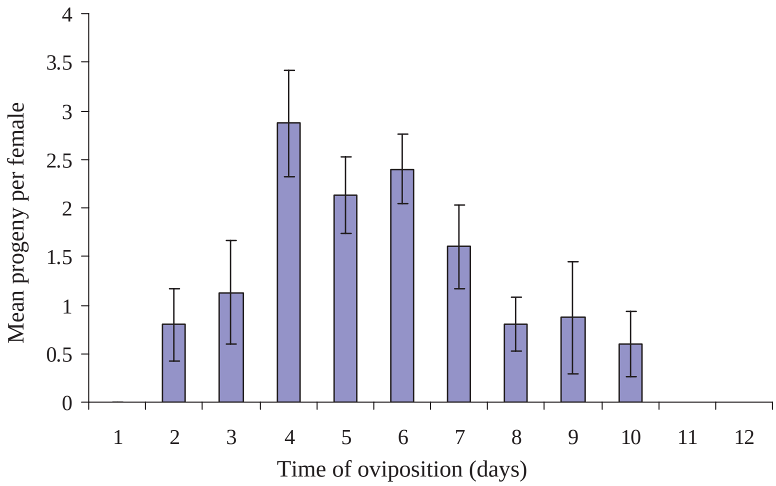

Figure 5 Mean progeny per female as related to time of oviposition of *Megastigmus thitipornae*. The vertical bars indicate standard error.

biological control because individuals live longer and can reproduce when there is a lower density of the host population.

The reasons the realized fecundity of *M. thitipornae* was determined by counting the total number of emerging progeny over the lifetime of an adult female and expressing it in terms of progeny per female, were: the eggs of *M. thitipornae* were laid on the host which were in the plant tissues and, thus, they were difficult to detect; counting the total number of eggs of this parasitoid in the plant tissues was laborious because plant microtechniques had to be used; and a number of eggs of this parasitoid might be dead at the time of oviposition time and these could not be observed.

However, there were several factors which might be of concern with synovigenic parasitoids. Gordh *et al*. (1999) reported that temperature and humidity influenced oviposition capacity and the efficiency of parasitoids. Nutrition might have effects on the length of life and the reproductive success of female parasitoids (Jervis *et al*., 1996). In natural environments, synovigenic parasitoids might exploit both host food (haemolymph) and non-host food, such as the nectar and honey dew of plants. Host-feeding prolonged female life and supplied the females with materials for continued egg production and for somatic maintenance (Jervis and Kidd, 1986). The parasitic Hymenoptera that do not feed on a host naturally, produce mature eggs by feeding on a source of carbohydrate, such as honey, nectar and pollen (Waage *et al*., 1985; Jervis *et al*., 1996).

In the case of *M. thitipornae*, the larvae of *L. invasa* developed in the gall of plant tissues. Thus, the adult parasitoid could not feed on the haemolymph of the larvae living inside the galls. Consequently, it was possible that *M. thitipornae* might alternatively feed on natural honey and nectar in nearby plant flowers in *E. camaldulensis* plantations.

In the ventilated greenhouse, it was noticed at emergence time that the ratio of average number of female to male progeny was 4.33:8.87, or approximately 1:2. Thus, the female to male progeny of *M. thitipornae* exhibit a male-biased sex ratio.

Determination of the sex ratio in the greenhouse compared to the natural environment might give different results. It was also noticed from this study that the numbers of both female and male *M. thitipornae* were not abundant on the shoots of small *E. camaldulensis* planted in pots and placed outside the greenhouse.

Etzel and Legner (1999) reported from their prolonged culture of parasitoids that the change in sex ratio of the parasitoids was rather complex. There were many factors contributing to the male-bias sex ratio (Fuester *et al.*, 2003). They reported that if the females were exposed to hosts too soon after mating, the sex ratio in their progenies might be male-biased. Waage *et al*. (1985) reported that female parasitoids tended to lay male eggs in small hosts. Thus, future studies on the sex ratio of the progenies of *M. thitipornae* in the greenhouse, or under prolonged culture, should focus on the factors affecting the sex ratio of the progeny of this parasitoid.

Development of *M. thitipornae*

Under natural conditions, the eggs of *L. invasa* develop in the leaf-galls of *E. camaldulensis*. Thus, the adult female of *M. thitipornae* had to explore the host and then oviposited a single egg on its host, since the female was aged 2 d after emergence. The results revealed that *M. thitipornae* parasitized the mature larvae and pupae of the host (Table 2).

The single egg of *M. thitipornae* developed as a solitary ectoparasitoid (Figure 6) and completed its development outside the host body. Solitary parasitism is a phenomenon in which a parasitoid egg completes development in one host (Gordh *et al.,* 1999). The mature larva or the pupa of *L. invasa* parasitized by *M. thitipornae* gradually became soft, changed body color to dark brown, and dried out. Finally, only the remains of the integument of *L. invasa* was left inside the leaf-gall chamber. The larva of *M. thitipornae* also developed to the last stage on it host within the leaf-gall chamber and emerged from the gall later.

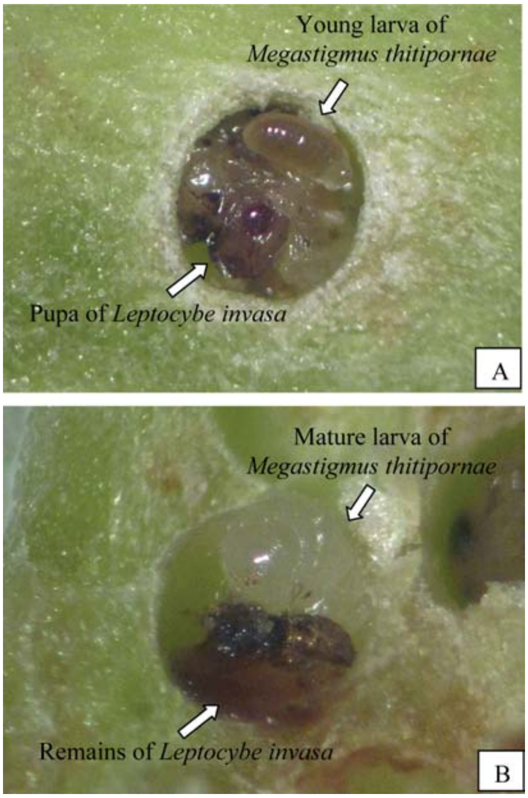

Figure 6 A solitary ectoparasitoid of *Megastigmus thitipornae*: (A) Young larva of the parasitoid developed on the pupa of *L. invasa*; and (B) Mature larva of *M. thitipornae* on the remains of *L. invasa* pupa.

Table 2 Preference of *Megastigmus thitipornae* to parasitize in different stages of development of *Leptocybe invasa*.

Development of *L. invasa*	Number of individuals	
	Emerging *L. invasa*	Emerging *Megastigmus thitipornae*
Stage 1 (egg)	193	0
Stage 2 (young larva)	278	0
Stage 3 (mature larva)	217	3
Stage 4 (pupa)	152	5

In a ventilated greenhouse, it was found that the mean developmental time of *M. thitipornae*, from the egg to the adult stage (or emergence stage), was 17.00 ± 0.44 d, ranging from 12 to 32 d (Figure 7). It was shortest in the egg stage with 1.87 d and longest in the pupal stages with 12.38 d.

The developmental time of *M. thitipornae* in this study was shorter than that of *Megastigmus* sp.-I in Israel which took 41–43 d in the greenhouse under a temperature regime of 23–31 °C (Protasov *et al*., 2008). The developmental time of *Megastigmus* probably varied with species and the experimental conditions. The ventilated greenhouse in the current research was warm and moist with a temperature regime of 26–33 °C.

The biological parameters of *M. thitipornae* are summarized in Table 3. The parameters were also compared to those of *L. invasa* reported by Sangtongpraow *et al*. (2011). The results showed the advantages and disadvantages of this parasitoid when compared to its host. The advantages of *M. thitipornae* from this research were the greater longevity and 50% survival period, its life-history strategy and the shorter developmental time from egg to adult. At the same time, the potential fecundity, realized fecundity and the sex ratio pattern were disadvantages of *M. thitipornae* when compared to those of *L. invasa*.

The biological parameters of *M. thitipornae* from the current study and of *L. invasa* from the previous study were also investigated under similar environments in the laboratory and the greenhouse. Thus, the findings from this research could indicate that *M. thitipornae* had

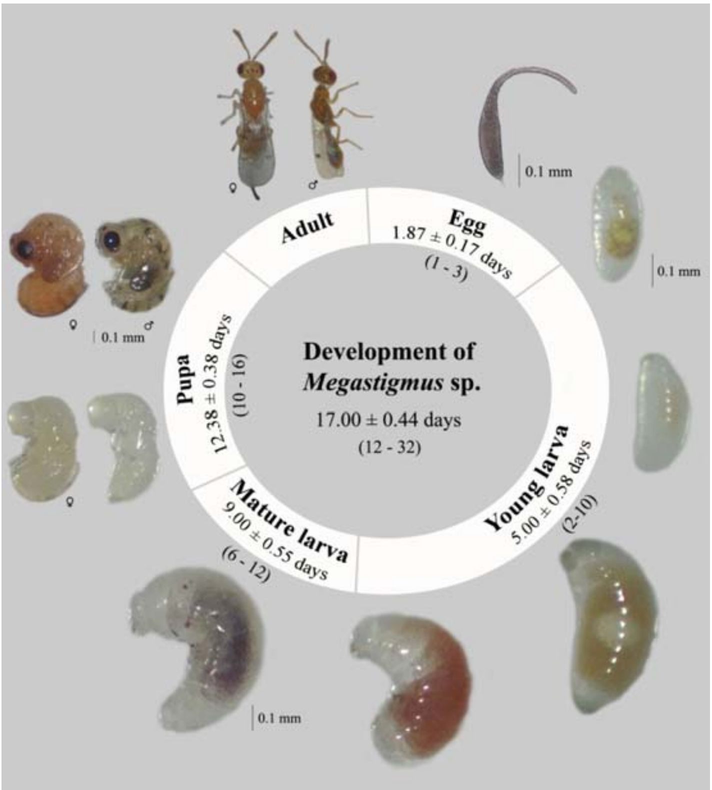

Figure 7 Development cycle of *Megastigmus thitipornae* on *Leptocybe invasa*. Values are shown as mean ± SE; range is shown in parentheses = (minimum - maximum).

less parasitism capacity to control *L. invasa* in Thailand. However, further study should focus on the factors affecting some disadvantages of *M. thitipornae* before making decisions on mass rearing of this parasitoid.

The findings which were new and have been first documented on *M. thitipornae* associated with eucalyptus galls, were: the longevity and survival patterns of females and males fed different diets, the potential and realized fecundities, confirmation that it is a synovigenic species, the sex ratio of the progeny in the greenhouse and the development of *M. thitipornae*.

CONCLUSION

The findings from the experiments in the laboratory showed that a honey solution diet could extend the mean longevity of female *M. thitipornae* to 9.83 ± 0.60 d and that of males to 7.83 ± 0.48 d. The estimated 50% survival periods for females and males when fed with this diet were 8 and 4 d. The average potential fecundity (egg load) of females was 2.98 ± 0.11 eggs per female. The average female size (hind tibia length) was 0.31 ± 0.002 mm. In the greenhouse, the mean realized fecundity of females was 13.20

Table 3 Biological parameters and parasitism capacity of *Megastigmus thitipornae*, the local parasitoid of *Leptocybe invasa* in Thailand.

Biological parameter	*Megastigmus thitipornae*	*Leptocybe invasa* [3]	Parasitism capacity of *M. thitipornae* [4]
Mean longevity of adult (days) [1, 5]			
Female	9.83	7.67	+
Male	7.83	5.67	+
Estimated 50% survival period (days) [1, 5]			
Female	8	5	+
Male	4	4	+
Fecundity of adult			
1) Mean potential fecundity of female (eggs per female) [1]	2.98	158.70	-
2) Mean realized fecundity of female (progeny per female) [2]	13.20	61.53	-
3) Life-history strategy [2]	Synovigenic sp.	Pro-ovigenic sp.	+
4) Sex ratio pattern (female progeny:male progeny) [2]	Male-biased	2:1	-
Development [2]			
1) Egg development	On mature larva and pupa (ectoparasitoid)	In leaf tissue	
2) Mean developmental time from egg to adult (days)	17.00	45.96	+

[1] = In laboratory.
[2] = In ventilated greenhouse.
[3] = From Sangtongpraow *et al.* (2011).
[4] = Positive symbols represent greater parasitism capacity while negative symbols indicate less capacity.
[5] = Fed with honey solution.

± 1.95 progeny per female. *M. thitipornae* was confirmed as a synovigenic species. The progeny of this parasitoid showed a male-biased sex ratio. The parasitoid parasitized the mature larvae and pupae of the host. A single egg of *M. thitipornae* developed as a solitary ectoparasitoid. The mean developmental time of this parasitoid, from the egg to the adult stage, was 17 ± 0.44 d. When these biological parameters of *M. thitipornae* were compared with those of *L. invasa* from a previous study, the results indicated that *M. thitipornae* has less parasitism capacity to control the eucalyptus gall wasp (*L. invasa*) in Thailand. However, this finding came from experiments in the laboratory and greenhouse. Thus, it is suggested to study the factors affecting some disadvantages of this parasitoid before making any decision on mass rearing of *M. thitipornae*.

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