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LIFE HISTORY AND FEEDING BEHAVIOUR OF THE OIL PALM BAGWORM, *Metisa plana* Walker (Lepidoptera: Psychidae)

Keywords: *Metisa plana*; Psychidae; life history; sexual dimorphism; oil palm; *Elaeis guineensis*.

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Bagworms were reared in a controlled environment room (CER) to obtain details of their life history. Eggs were pale yellow and barrel-shaped, and their incubation period was 19.7 ± 0.3 days. Fecundity of laboratory-reared females was higher than that of wild-caught females (158.3 ± 10.3 vs 99.9 ± 5.7 eggs / ♀) yet lower than those recorded for several other species of Psychidae. Fertility was high (generally > 90%). Sexual dimorphism in instar number was recorded (5–6 for males vs 6–7 for females). Head capsule widths, bag lengths and morphology can be used to determine instars.

Most leaf tissue removed from oil palm foliage (66.8%) was used for maintenance and body growth, and the remainder for bag construction. Larvae preferred upper leaf surface for feeding and lower surface for resting and moulting.

Sexual dimorphism was also noted in pupal size (males smaller than females) and developmental time (males, 21.4 ± 0.3 days; females, 10.0 ± 0.4 days). Total developmental times of males and females did not differ, suggesting that overlapping generations are not a requisite for an outbreak. Sex ratio was male-biased (8.5:1).

INTRODUCTION

Bagworms are larve that live in individual cases or bags, which they construct from the first instar. They remain in their bags until the adult stage for females and the pupal stage for males. Generally, bagworms are defoliators and are known

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to be important pests of various crops such as pine (Heather, 1976) and *Albizia* (Nair *et al.*, 1981).

The bagworm, *Metisa plana* Walker (Lepira: Psychidae) is the most important occasional pest of oil palms in Malaysia because of its potential to reach outbreak proportions. Many cases of bagworm outbreaks have been reported, including 34 cases affecting 11 900 ha, 1975–1980 (Wood, 1982) and 98 cases affecting 37 102 ha, 1981–1985 (Basri *et al.*, 1988). Information on recent outbreaks has not been documented. Crop loss from a moderate defoliation can be severe. Wood *et al.* (1973) showed that 50% simulated damage resulted in a yield loss of 43 per cent. Further, Basri (1993) showed that a crop loss of 44% could occur in palms with medium natural damage (estimated extent of defoliation was 10%–13%; highest affected fronds, fronds 2–6).

Information on the full life cycle of *M. plana* is essential for sound management of this pest. With such information, weaknesses in the life cycle can be determined and exploited for the control of the pest. Further, the information allows for the qualitative and quantitative recording of field data and subsequently assists in the timing of control operations. Information on the life cycle also provides a better understanding of the biology of the pest for the purpose of pest management.

Some studies on the life cycle of *M. plana* were reported by Wood (1966), and later by Syed (1978), but with different results, particularly on the number of instars. Further, some biological details have remained unknown, such as fecundity, egg fertility, duration of larvae and pupae, adult longevity, sexual dimorphism and sex-ratio of adults. In this paper, the authors examine the life cycle of *M. plana* and report on the biological details mentioned.

MATERIALS AND METHODS

The study was conducted in the laboratory at PORIM Headquarters, in Bangi.

Eggs

Eggs, still in pupal bags, were collected from the field. Lengths and widths of 30 eggs were measured and their shape, colour and texture recorded.

In a controlled environment room (CER) [day temperature 27 ± 1°C; night temperature 24 ± 1°C; Light: Darkness = 12:12 hours; humidity 30%–50% RH], a male was introduced into a rearing cylinder containing a receptive female. The male was replaced after two days if the female was still receptive. The receptivity of the female was determined by examining the anterior opening of its pupal bag; intermittent protrusion of the head and thorax indicated its receptivity. Once mated, the female partially closed the anterior opening of its pupal bag. The pupal bag was observed until eggs hatched. This procedure was repeated for ten females. The time taken from mating to egg hatch represented an estimate of the incubation period.

In the field, 12 bags containing receptive females were hung inside separate delta traps similar to those used for pheromone traps. The delta traps were hung at an estate in Selangor (Estate BC) on a frond rachis about 9 m from the ground. After two nights, the females were placed in separate rearing cylinders in the CER and inspected daily for subsequent hatching of oviposited eggs.

A total of 158 female pupal bags was collected from plots at PORIM Research Station in Kluang on 10 April 1990. Each bag was placed in a cylinder with a leaflet segment on 16 April and held in the CER. All cylinders were inspected daily for newly hatched larvae. When egg hatch ceased, the pupal bags were cut open and the number of unhatched eggs and larvae which failed to leave their parental bags was recorded. The total number of eggs laid by each female (fecundity) and the proportion of eggs which hatched (fertility) were calculated. Another fifteen female pupal bags were collected from PORIM Research Station, Kluang on 19 June 1990 and inspected for newly-hatched larvae for the purpose of determining fecundity.

Larvae

Four newly-emerged larvae were placed on the upper surface of a fresh piece of leaflet in a glass Petri dish. Bag construction was observed every five minutes under a microscope until at least one larva had completed making its bag. Observations were also made to determine how the larva attached the small, round pieces of leaf to its bag. Six second instars were selected and placed separately in rearing cylinders and observed every 15 minutes.

For the laboratory study, eggs were collected

from the field on three separate occasions for the establishment of bagworm colonies. The first colony was established by collecting pupal bags with eggs from Estate BC on 22 December 1987. The following day, 140 newly-hatched larvae were placed on standardized segments of leaflets and reared through pupation to adult emergence.

Leaflet segments were prepared by removing a middle frond from a palm and cutting the leaflets from the rachis. Segments measuring 22.5 cm in length from the middle part of the frond were cut from the lower one-third of the leaflets and they were then washed with water. The lower parts of the segments were trimmed to a width of about 4 cm and pushed through a 4.2 cm slit in a plastic vial cover, which was then placed over a plastic vial (4.5 cm diameter × 8.5 cm height), almost filled with water. The upper 14 cm of the leaflet segment was therefore exposed for larval feeding.

Ten first instars were placed in each of 14 vials. Each vial was then put in a plastic rearing cylinder (13 cm diameter × 24 cm height). All cylinders were placed in the CER. The leaflet segments were replaced once each week.

From 2 to 17 larvae were sampled at random at 4 to 21-day intervals and killed with ethyl acetate. For each larva, the length of the bag and the width of the head capsule were measured. Bag length was based on the relatively hard structure which formed the foundation of the bag (*Figure 1, A* to *D*). The length of the bag was measured with a graduated ocular microscope.

After recording the lengths, the bags were cut open with a pair of fine scissors, larvae were removed and the width of the head capsule was measured under a microscope. Means of the bag lengths and head capsule widths were then calculated for each instar. Larvae were assigned to different instars when the measurements of head capsule widths were greater than those of the previous instars. The occurrence of inactivity associated with moulting (1–3 days) facilitated such determinations. These measurements were later confirmed by data from a third colony (see later), in which the discarded head capsules of individual larvae were collected and measured for successive instars till pupation. Because the bag length and head capsule width for any larva were measured simultaneously, the stage determined based on head capsule width was used for the bag length as well.

A second colony was established by collecting 397 female pupal bags from Estate BC on 12 March 1988. The bags were randomly divided into six batches and each batch was separately placed in an empty rearing cylinder in the controlled rearing room and observed for hatching. From larvae that hatched between 15 and 17 March, 1080 larvae were randomly selected to ensure as much genetic variability in the sample as possible.

A total of 216 leaflet segments was prepared, and five newly-hatched larvae were placed on each of them. Thirty-six vials were then placed in each of six large aluminium cages (0.61 × 0.61 × 0.61 m). Each cage was covered with thin transparent plastic to reduce desiccation of the leaflet segments. The larvae were provided with fresh leaflets twice a week and the cages were regularly cleaned.

From the laboratory colony, four separate batches containing 28–50 newly-hatched larvae were weighed. A further three batches of 10, 10 and 20 larvae were sampled randomly every two days during the first week of the study. For each batch, only one larva was taken from a vial. The larvae were then killed and bag length and head capsule width were measured. Each batch of larvae and empty bags was separately weighed. The weight of each batch divided by the number of individuals per batch represented the mean weight of the larva and the bag of the first instars. A similar procedure of sampling and weighing was carried out for second instars, except that four batches of five larvae each were taken from the laboratory population. For subsequent instars, five larvae were sampled twice every week and larvae were weighed individually and their head capsules measured.

The third colony was established in February 1989 by individually rearing 211 newly-hatched larvae on leaflet segments in rearing cylinders. These larvae were the offspring of two females from a population of bagworms in Perak (Estate FTU). Each cylinder was inspected daily for discarded head capsules. The widths of the head capsules were measured and the dates of collection recorded. The head capsules of the final male instar were collected several days after formation of pupal bags. Females did not discard their final head capsules, so in this case the data were obtained by destructive sampling of live larvae from the second colony.

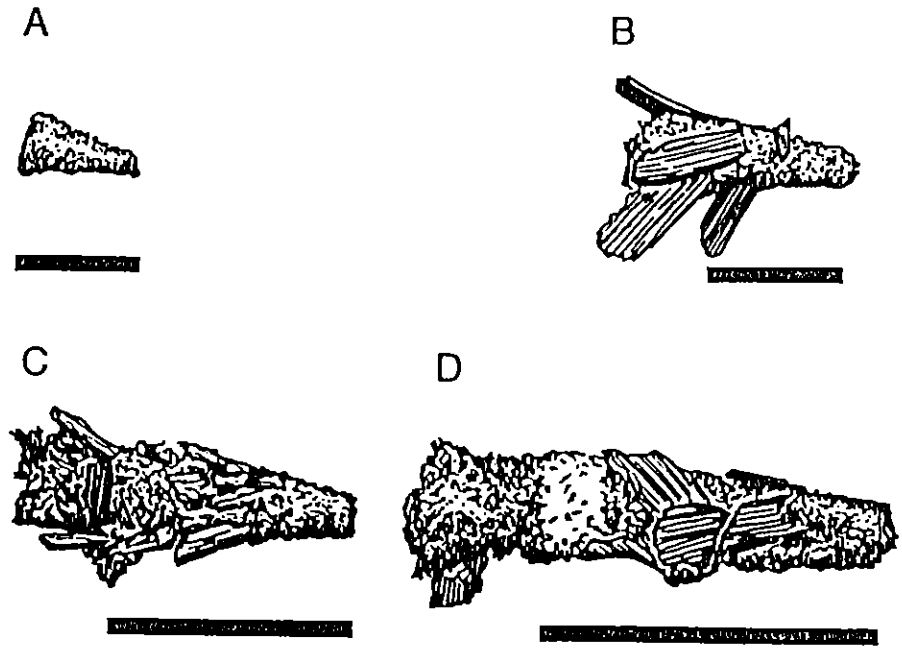

Figure 1. Specification of bag length for Metisa plana *as indicated by the solid horizontal bar. Examples are shown for: A : First; B : Third; C : Fifth; and D : Sixth instar.*

The duration of each instar was determined by calculating the number of days between the dates of finding a discarded head capsule and the subsequent capsule. Not all discarded head capsules could be found, but enough were obtained to determine the larval duration of various instars. For those larvae which reached the pupal stage, the data were grouped under male and female. Durations of each instar for males and females were determined and compared using a t-test to indicate whether or not there was any difference. Bags of all larvae were measured every other day. Lengths of male and female bags were determined and analysed for difference. Instar duration was also determined by individually rearing 100 newly-hatched larvae (fourth colony) up to pupation.

Twenty newly-hatched larvae were individually reared to pupation on leaflet segments. Bag lengths, feeding activity, inactive periods, the surface on which they were found, and the presence of discarded head capsules were recorded daily. The proportion of the larvae found on the upper and lower leaflet surfaces was determined for all larval stages during the active and inactive periods.

Pupae and adults

The duration of the male pupal stage was determined by recording the period (days) between formation of the pupal bag and emergence of the adult. For the female, the duration of the pupal stage was estimated based on the time from the formation of the pupal bag to the first presence of a small round opening at the anterior end of the bag, through which intermittent protrusion of the female's head subsequently occurred. Therefore, this estimate also included the duration of the prepupal stage. Female and male longevity were determined using individuals from the third colony. For the females, only virgins were used.

RESULTS

Eggs

The eggs were pale yellow, barrel-shaped (0.71 ± 0.01 mm and 0.47 ± 0.01 mm) and had a smooth-surfaced chorion. They became brownish when close to hatching. The average duration of the incubation period, which represented the time from mating to egg hatch was 19.7 ± 0.3 days (*Table 1*). Hatching of eggs was completed within a few days for each individual adult.

Of 158 female pupal bags collected on 10 April 1990, 68 contained eggs. Mean fecundity was estimated to be 98.6 ± 6.4 (range of 11 to 247) and mean fertility was 93.4 ± 1.8% (range of 13.3% to 100%). From samples collected on 19 June 1990, the average fecundity of 15 females was 105.7 ± 12.5, with a range of 31 to 178 eggs. Dissection of all pupal bags revealed that 9.6% of newly-hatched larvae failed to leave their parental bags and consequently died. For females collected on 10 April, 88.2% remained inside their pupal bags after oviposition. For those of 19 June, 73.3% remained. There was no significant difference in fecundity between females collected on either date ($t = 0.479$, $df = 81$, $p > 0.05$) and a mean fecundity representative of a field population could be considered as 99.9 ± 5.7 eggs/female.

The fecundity and fertility of individuals reared in the laboratory were also determined. From a sample size of 22 females, mean fecundity was 158.3 ± 10.3 eggs, with a range of 92 to 228, and mean fertility was 99.4 ± 0.2%. The average time taken for all eggs from each individual female adult to hatch was 3.0 ± 0.3 days. As in the case of the field data, a high proportion of the adult females (80.9%) did not vacate their bags after oviposition.

Larvae

Bag construction was similar in shape and structure for all instars. On hatching, a first instar crawled out of the pupal bag through the opening (about 0.3 mm in diameter) at the anterior end, which was covered with silk. The larva cut out a tiny spindle of tissue from the leaf surface and fastened it with silk on to the anterior part of its abdomen. Each spindle measured 0.24 mm × 0.06 mm, with both ends tapered. Additional spindles were cut off by the larva and fastened next to the previous one. Eventually, the anterior half of the abdomen was covered by a mass of longitudinally arranged leaf spindles, which formed the framework for further bag construction. The larva continued its bag construction and after about one hour almost the whole abdomen and thorax were covered by the bag. There was a relatively wide hole at the posterior end of the bag and construction was completed after about two hours. At this stage, the head of the larva was covered and the bag opening at the posterior end had become smaller than before, presumably by deposition of more leaf spindles. The new bag had a greenish to light brown colour and a relatively smooth appearance. The larva remained on the same spot to complete its bag construction. Feeding occurred half an hour after completion of construction, adjacent to the area where spindles were removed.

TABLE 1. EGG INCUBATION PERIOD OF *Metisa plana* IN A CONTROLLED REARING ROOM AT PORIM, BANGI*

Days to commencement of egg hatch from mating	Number of females observed
16	1
18	3
19	6
20	5
21	5
22	2
Mean (±SE) 19.7 (±0.3)	Total 22

*Day and night temperatures 27 ± 1°C and 24.1°C, respectively; relative humidity 35–50 percent.

The second instar fed on the same spot, producing a small scraped area. The scraped spot was then cut out by the larva feeding on its margin. The spot was then fastened with silk to the anterior part of the bags, with the scraped surface facing inwards. This process took about three hours, leaving a round hole on the leaflet.

Mean widths of head capsules obtained from three groups of larvae did not differ (*Table 2*). It was evident that there were up to seven instars, with successive growth ratios for each succeeding instar of 1.34, 1.41, 1.45, 1.40, 1.24 and 1.18, respectively. The average ratio was 1.34 ± 0.04. The application of Dyar's rule (1890) to the above data confirmed that there were up to seven instars for *M. plana* (that is, the larval head capsule width follows a regular geometric progression for its successive stages). However, closer study showed that the number of instars for male and female larvae differed based on the time of pupation and the width of the final head capsules discarded before pupation. Males had five or six instars, whereas females had up to six or seven instars. Only a small number of individuals from the second colony that were females attained the seventh instar to provide head capsule measurements (*Table 2*).

Head capsule widths of male and female larvae were similar from the first to the fifth instar (*Table 3*), but at the sixth instar, the head capsule of the female was significantly ($t = 2.913$, $df = 26$, $p < 0.01$) broader than that of the male. However, sexual discrimination was not possible at the sixth instar because the range in widths overlapped (male, 1.24–1.46 mm; female, 1.31–1.56 mm).

There was a continual increase in bag length except when the larvae became inactive prior to moulting (*Table 4*). Bag length differed between the two colonies examined for first ($t = 2.759$, $df = 51$, $p < 0.01$), second ($t = 3.846$, $df = 36$, $p < 0.01$), fourth ($t = 3.811$, $df = 41$, $p < 0.01$), and fifth instars ($t = 3.130$, $df = 45$, $p < 0.01$) (*Table 4*). This can be explained by a difference in sampling frequency between the two studies. In the first study, sampling was concentrated at the beginning of each stage, but in the second, samples were taken at least twice a week, and the results represented the average length during each instar. Bag length can be used to determine instar because the lengths generally do not overlap (*Table 4*).

Results from the third colony showed no significant difference in bag length between male and female larvae, at the first to the sixth instars, with the exception of the fifth ($t = 2.186$, $df = 30$, $p < 0.05$) (*Figure 2A*). In another experiment, no significant differences were observed (*Figure 2B*). From these two sets of data, it is obvious that there is no sexual dimorphism in the *length* of the bag.

Differences in developmental time for larvae reared from two groups of eggs were found only in the first ($t = 2.874$, $df = 74$, $p < 0.05$) and seventh ($t = 2.281$, $df = 19$, $p < 0.05$) instars. There was little difference in larval development time between the two studies (*Table 5*).

Larval development times for males and females in the two groups were 48.7 and 59.4, and 45.9 and 58.7 days, respectively. No difference was apparent between male and female instar durations in either group except for the fourth in the third colony and the sixth in the fourth colony. For the sixth instar, the sample size was inevitably low, and hence it is difficult to draw any meaningful conclusion (*Table 6*). About 11–13 days were required for the additional instar in female larvae.

Most leaf tissue removed from oil palm (66.8%) was used for maintenance and body growth but a substantial fraction (33.2%) was used for bag construction (*Figure 3*). However, during the second and third instars, slightly more leaf tissue was used for bag construction than for consumption.

The first four instars fed mainly by scraping the leaf surface and removing small pieces of scraped lamina for bag construction. Fifth instars removed a larger area of leaf tissue by scraping than did the earlier instars, and the amount of lamina cut increased. During the sixth instar, larvae removed more lamina for consumption and leaf scraping was much less. With the exception of the seventh instars, larvae preferred to feed on the upper surface of leaflets (*Figure 4A*). During moulting, larvae beyond third instars attached themselves to the lower surface (*Figure 4B*) with increasing frequency as they matured.

Frass pellets varied in size from about 0.16 mm for the first to 1.42 mm for the seventh instar.

TABLE 2. HEAD CAPSULE WIDTH (mm) OF VARIOUS INSTARS OF *Metisa plana* AT PORIM, BANGI

Instar	First colony		Second colony		Third colony		Combination of three colonies		
	n	$\bar{x}$ ± S.E	n	$\bar{x}$ ± S.E	n	$\bar{x}$ ± S.E	n	$\bar{x}$ ± S.E	Range
I	13	0.30 ± 0.012	90	0.29 ± 0.002	20	0.29 ± 0.002	123	0.29 ± 0.002	0.28 –0.37
II	10	0.39 ± 0.01	28	0.39 ± 0.005	20	0.40 ± 0.003	58	0.39 0.003	0.34 –0.44
III	2	0.60 ± 0	22	0.53 ± 0.009	22	0.55 ± 0.007	46	0.55 ± 0.006	0.48 –0.68
IV	17	0.79 ± 0.02	26	0.81 ± 0.017	27	0.79 ± 0.009	70	0.80 ± 0.008	0.68 –0.98
V	10	1.07 ± 0.03	37	1.13 ± 0.014	12	1.14 ± 0.017	59	1.12 ± 0.011	0.95 –1.26
VI	13	1.41 ± 0.02	35	1.40 ± 0.014	28	1.36 ± 0.017	76	1.39 ± 0.082	1.22 –1.58
VII	–	–	9	1.64 ± 0.018	–	–	9	1.64	1.60 ± 0.018 –1.77

n number
S.E. standard error
$\bar{x}$ mean head capsule width
Seventh instar data for the first colony as well as the third colony are not available because none of the individuals reached this stage. This is related to the much lower starting number of larvae in both colonies, compared with the second colony.

TABLE 3. HEAD CAPSULE WIDTH (mm) OF THE MALE AND FEMALE LARVAE OF *Metisa plana* FROM THE THIRD COLONY AT PORIM, BANGI

Instar	Male larvae		Female larvae		t-test result
	n	$\bar{x}$ + S.E.	n	$\bar{x}$ + S.E.	
I	13	0.29 ± 0.002	13	0.28 ± 0.002	ns
II	17	0.40 ± 0.003	14	0.40 ± 0.004	ns
III	18	0.56 ± 0.006	13	0.56 ± 0.014	ns
IV	14	0.79 ± 0.012	13	0.80 ± 0.013	ns
V	18	1.13 ± 0.017	10	1.15 ± 0.016	ns
VI	18	1.33 ± 0.019	10	1.42 ± 0.025	**

n number of cases
S.E. standard error
$\bar{x}$ mean head capsule width
ns not significant
** significant at the 1% level

TABLE 4. BAG LENGTH (mm) OF VARIOUS INSTARS OF *Metisa plana* IN THE STUDY ON LIFE HISTORY AT PORIM, BANGI

Instar	First colony			Second colony			t-result
	n	$\bar{x}$ ± S.E	Range	n	$\bar{x}$ ± S.E	Range	
I	13	1.9 ± 0.09	1.3–2.5	40	2.2 ± 0.06	1.3–3.0	**
II	10	2.6 ± 0.11	2.2–3.2	28	3.2 ± 0.08	2.6–4.1	**
III	2	4.0 ± 0.45	3.5–4.4	22	4.4 ± 0.16	3.2–6.0	ns
IV	17	5.2 ± 0.14	4.4–6.5	26	6.0 ± 0.15	4.9–6.6	**
V	10	8.0 ± 0.21	7.3–8.8	37	7.1 ± 0.14	5.3–8.9	**
VI	13	8.4 ± 0.21	7.6–10.1	35	8.7 ± 0.10	7.5–10.0	ns
VII		N.A.		9	10.1 ± 0.24	9.3–11.0	–

n number of cases
N.A. data not available
S.E. standard error
ns not significant
$\bar{x}$ mean bag length
** significant at the 1% level

Pupae and adults

The male pupal bag could be distinguished from that of the female as the former was significantly shorter in length (8.24 ± 0.18 *vs* 11.75 ± 0.36 mm) ($t = 8.667$, $df = 18$, $p < 0.001$) and narrower in maximum width (2.27 ± 0.04 *vs* 3.02 ± 0.02 mm) ($t = 14.423$, $df = 18$, $p < 0.001$) (*Figure 5*).

The duration of the male pupal stage averaged 21.4 ± 0.3 days; females required 10.0 ± 0.4 days (*Table 7*). The shorter period required for pupation in the female compensated for the longer period of larval development.

The adult males had a wing span of about 12 mm (*Figure 5*). In the laboratory, they had a life span of about 1 to 2 days. The adult females are wingless and were found as early as the eighth day after the formation of the pupal bag (*Figure 5*). Laboratory observations revealed that they had a life span of about seven days, three and a half times longer than that of the male. Male to female sex ratios from the first and second colonies were 6.5:1 (13♂: 2♀) and 9.5:1 (38♂: 4♀), respectively and the combined sex ratio was 8.5:1 (51♂: 6♀).

There were no significant differences in life span from eggs to emergence of adults between males and females whether with minimal or maximal number of instars: minimum, *i.e.* ♂ with 5 instars, ♀ with 6 instars (82.4 ± 0.8 *vs* 83.9 ± 1.9 days); $t = 0.868$, $df = 35$, $p > 0.05$; maximum, *i.e.* ♂ with 6 instars, ♀ with 7 instars (90.5 ± 1.3 *vs* 90.0 ± 1.2 days); $t = 0.277$, $df = 55$, $p > 0.05$ (*Figure 5*). These results suggest that both male and female adults will emerge at about the same time. Overall, the average total life cycle of *M. plana* could vary from 2.7 to 3 months.

DISCUSSION

Eggs of *M.plana* were similar in shape and colour to those of *Thyridopteryx ephemeraeformis* (Haworth) and *Clania cramerii* (Westwood) but were slightly smaller. Eggs of both *T. ephemeraeformis* and *C. cramerii* were barrel-shaped and pale yellow in colour, but their respective sizes were 0.8 × 1.0 mm and 0.90 × 0.59 mm (Kaufmann, 1968; Thangavelu and Ravindranath, 1985).

Dissection of all pupal bags revealed that 9.6% of newly-hatched larvae failed to leave their parental

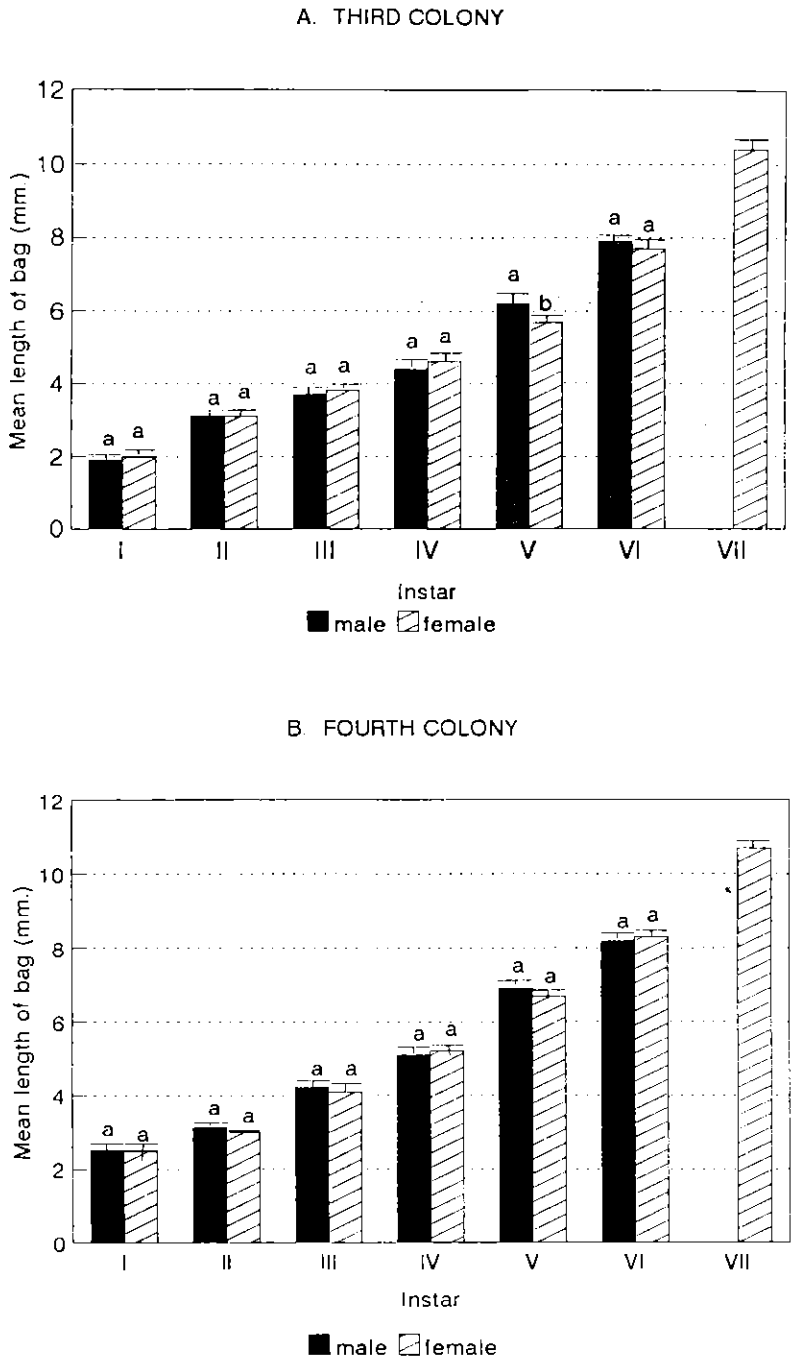

Figure 2. Mean Bag Length of the male and female larvae of Metisa plana *from two colonies; A and B. For each experiment, columns within the same instar marked by different letters are significantly different at* $p < 0.05$.

TABLE 5. INSTAR DURATIONS (days) FROM TWO LABORATORY COLONIES OF *Metisa plana* AT PORIM, KLUANG

Instar	Third colony		Fourth colony		t-test result	Mean of the two colonies	
	n	$\bar{x}$ ± S.E	n	$\bar{x}$ ± S.E		n	$\bar{x}$ ± S.E
I	49	8.5 ± 0.2	27	9.7 ± 0.4	**	76	8.9 ± 0.3
II	30	6.4 ± 0.3	27	6.7 ± 0.2	ns	57	6.6 ± 0.2
III	43	6.9 ± 0.1	27	6.2 ± 0.5	ns	70	6.6 ± 0.2
IV	37	8.5 ± 0.3	27	8.5 ± 0.6	ns	64	8.5 ± 0.2
V	28	9.7 ± 0.3	27	9.7 ± 0.8	ns	55	9.7 ± 0.4
VI	13	9.0 ± 0.6	18	9.8 ± 0.9	ns	31	9.5 ± 0.6
VII	10	9.2 ± 1.2	11	6.1 ± 0.7	*	21	7.6 ± 0.8

n number of cases
ns not significant
S.E. standard error
* significant at the 5% level
$\bar{x}$ mean instar duration
** significant at the 1% level

TABLE 6. INSTAR DURATIONS (days) OF THE MALE AND FEMALE *Metisa plana* AT PORIM, BANGI

Instar	Male larvae		Female larvae		t-test result
	n	$\bar{x}$ ± S.E	n	$\bar{x}$ ± S.E	
Third colony					
I	25	8.9 ± 0.4	24	8.1 ± 0.2	ns
II	14	6.1 ± 0.2	16	6.8 ± 0.5	ns
III	23	6.8 ± 0.2	20	7.0 ± 0.1	ns
IV	17	8.8 ± 0.2	20	8.3 ± 0.2	*
V	17	9.7 ± 0.5	11	9.8 ± 0.3	ns
VI	9	8.4 ± 0.7	4	10.3 ± 0.8	ns
VII	–	–	10	9.2 ± 1.2	–
Fourth colony					
I	13	9.3 ± 0.2	14	10.1 ± 0.8	ns
II	13	6.9 ± 0.1	14	6.6 ± 0.3	ns
III	13	5.9 ± 0.7	14	6.4 ± 0.7	ns
IV	13	8.1 ± 0.5	14	8.9 ± 1.0	ns
V	13	9.8 ± 1.1	14	9.7 ± 1.1	ns
VI	4	6.0 ± 1.7	14	10.9 ± 0.8	*
VII	–	–	11	6.1 ± 0.7	–

n number of cases
ns not significant
S.E. standard error
* significant at the 5% level
$\bar{x}$ mean instar duration

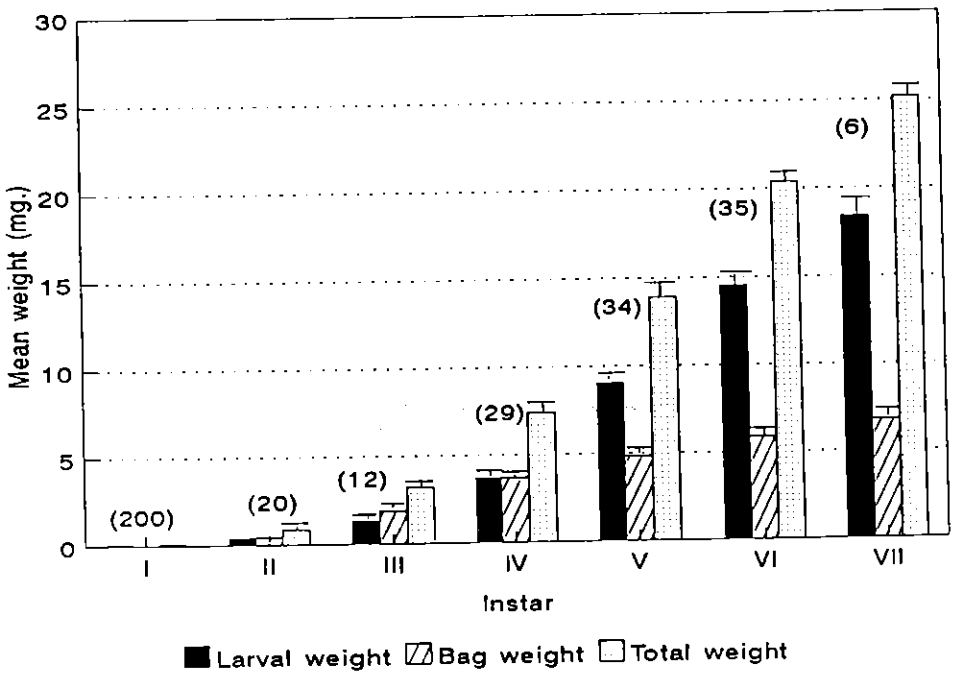

Figure 3. Growth of larva and bag of various instars of Metisa plana *in the laboratory at PORIM, Bangi. Numbers in parentheses represent the sample size for each instar.*

bags and consequently died. This mortality was probably related to several factors. On hatching, all larvae within a bag could only exit through the opening (about 0.3 mm in diameter) at the anterior end of the bag, which allowed only one larva to pass through at a time. Because hatching occurred over a relatively short period, competition between individuals could possibly occur, resulting in mortality. Larval mortality could be explained by starvation associated with crowded conditions and by the delay in leaving the bag.

The fecundity of females in the laboratory was significantly higher ($t = 4.758$, $df = 103$, $p < 0.01$) than that of field-collected individuals. This difference can perhaps be explained by eggs in the field being exposed to predation by natural enemies; PORIM (1990) reported that a predator, *Callimerus arcufer* Chapuis (Coleoptera: Cleridae) had been found in field collected eggs. It might also be that laboratory-reared larvae were better fed than those of the field, resulting in higher fecundity of females from the former.

The fecundity data obtained for *M. plana* in this study are in agreement with the range (100–300 eggs/female) reported by Wood (1968). Nevertheless, such fecundity may need to be continually checked because it may be affected by changes in the genetic constitution of a fluctuating population (Wellington, 1964). This may have an important effect on the mechanism of population regulation (Southwood, 1978).

Compared with other species of bagworm, *Mahasena corbetti* Tams, (fecundity, 2000–3000 eggs/female, Syed (1978)), *Eumeta variegata* Snellen (average fecundity, 3000 eggs/female, Yu(1990)) and *Pteroma plagiophleps* Hamps, (average fecundity, 1774 eggs/female, Howlader (1990)), the fecundity of *M. plana* is low. Thus, for an outbreak of *M. plana* to occur, more mated females per unit area may need to be present than would be the case with the other bagworm species.

Most females remained inside their pupal bags after oviposition. This finding is in contrast to those of Entwistle (1963), Kaufmann (1968), and Syed (1978) who noted that in six other species of psychids, the females left their pupal cases after oviposition. The species they studied were *Acanthopsyche sierricola* (White), *Eumeta cervina* Druce, *Eumeta rougeoti* Bourg., *Kotochalia junodi* (Heyl.), *T. ephemeraeformis*, and *M. corbetti*. It might be

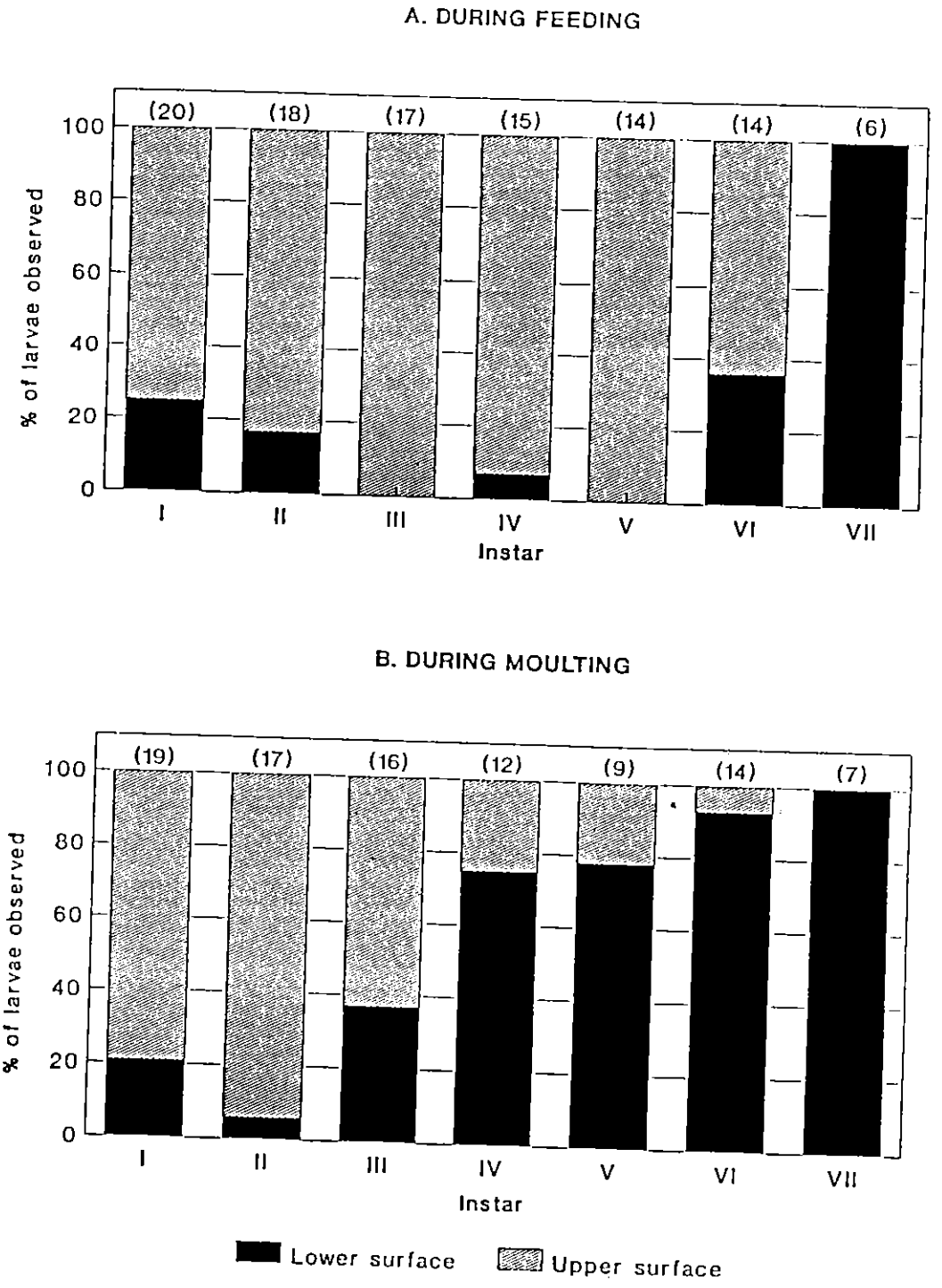

Figure 4. Leaf surface preference of the larvae of Metisa plana *(A) during feeding and (B) during moulting. Numbers in parentheses represent the number of observations.*

bags to ascertain whether some or most adults remained within their bags.

A sexual difference in the number of instars *M. plana* has been recorded in this study (5–6 for males *vs* 6–7 for females). Such a difference is probably related to the biology of the pest. Females need to lay eggs; hence, they need to accumulate sufficient food reserves for their offspring through more feeding growth. Further, because of the shorter duration of female pupae, females can afford to live longer as larvae, yet still maintaining synchronization with males (see later). This characteristic has not been reported in other species of psychids whose life histories have been studied. These include *Eumeta crameri* Westwood (Ameen and Sultana, 1977), *Hyalarcta huebneri* (Westwood) (Heather, 1975) and *T. ephemereformis* (Kaufmann, 1968). The synchrony of the life cycles of these species is probably maintained by climatic conditions.

Although Wood (1966) and Syed (1978) reported on the number of instars for *M. plana*, their findings were contradictory. Wood (1966) reported that there were four instars before pupation, but gave no details on sample sizes, or means or ranges of head capsule widths. Syed (1978), using *Cassia* sp. as the host plant, reported six instars. Although his findings were similar to ours, he gave no details on head capsule widths or on whether male and female larvae had a different number of instars.

The above difference may be accounted for by the types of food material offered to the larvae of *M. plana*. The foliage of *Cassia* sp. is probably tougher than that of oil palm seedlings. As a result, more feeding, growth and moulting occurs in larvae feeding on *Cassia* than in those feeding on oil palm. This suggestion is based on the findings of Bernays (1986) who found that the hardness of diet resulted in different morphometry and possibly a different number of instars. Thus for field application on the number of instars (*e.g.* study on population dynamics), our results would probably be more applicable than those of Wood (1966) and Syed (1978); we have used leaflets from mature palms but neither of the earlier workers did so.

Our results showed that the sexual difference in head capsule width at the sixth instar of *M. plana* could not be used to differentiate sexes because the ranges overlapped greatly. In constrast, a distinct sexual difference exists at the ninth instar for *C. cramerii* (Thangavelu and Ravindranath, 1985). Similar phenomena have not been reported in *T. ephemeraeformis* (Kaufmann, 1968). The lack of such information on Psychidae could be related to the difficulty of determining the time when moulting occurs because the cast exuviae are eaten by the larvae and the moulting process occurs within the bag (Davis, 1964; Thangavelu and Ravindranath, 1985).

Instar recognition of *M. plana* can be made by measuring the head capsule width of the larvae (*Table 2*). Similar findings have been reported for *C. cramerii* (Thangavelu and Ravindranath, 1985) and *T. ephemeraeformis* (Kaufmann, 1968). Nevertheless, in several other species, such an approach is not possible because measurements overlap broadly between instars; these species include the navel orange-worm *Amyelois transitella* (Walker) (Lepidoptera: Pyralidae) (Caltagirone *et al.*, 1983)

TABLE 7. PUPAL DURATION OF *Metisa plana* FROM THREE LABORATORY COLONIES AT PORIM, BANGI.

Pupal details	First colony	Second colony	Third colony
Male pupae			
n	13	38	23
$\bar{x}$ ± S.E.	22.5 ± 0.3	20.5 ± 0.2	22.2 ± 0.4
Female pupae			
n	not available	not available	37
$\bar{x}$ ± S.E.			10.0 ± 0.4

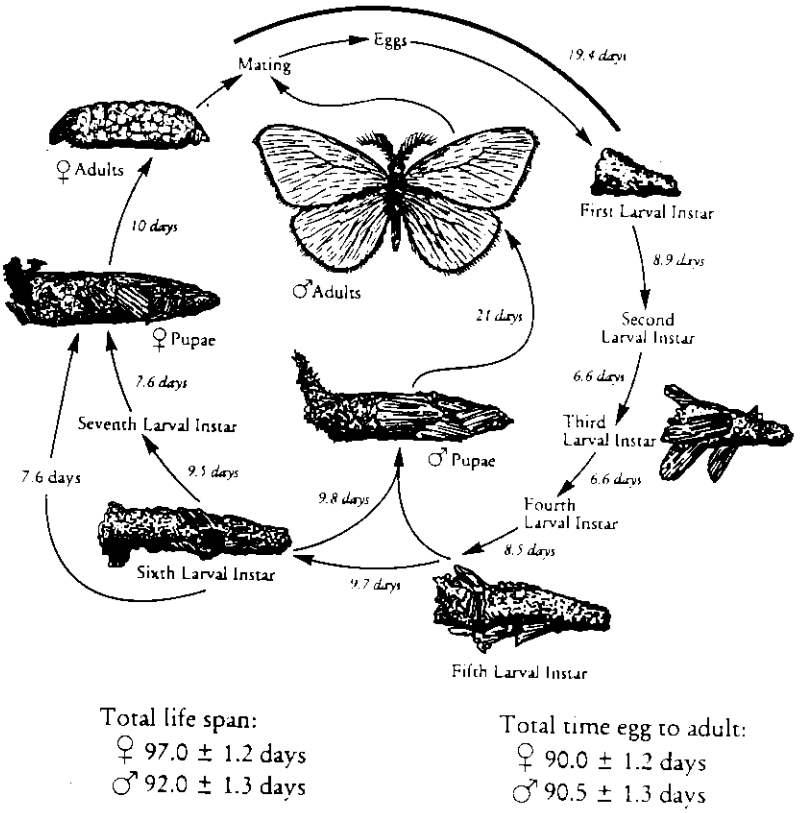

Figure 5. Life cycle of Metisa plana *under laboratory conditions.*

and the cat flea *Ctenocephalides felis* (Bouché), (Siphonaptera: Pulicidae) (Moser *et al.*, 1991).

Measurement of head capsule widths to determine instars of a field population of *M. plana* can be difficult because of the concealed nature of larvae. In this situation, bag length measurement can become useful. The accuracy of this technique can be improved by simultaneously examining the bag morphology of instars, which are rather distinct: Instar I, relatively smooth surface; Instar II, a few, round and small leaf pieces loosely attached at the anterior end of the bag; Instar III, larger, rectangular leaf pieces (up to 6) attached at the posterior end; Instar IV, many large, round to rectangular leaf pieces (7–13) loosely attached, producing a bushy appearance; Instar V, most loose leaf pieces have been plastered, giving the bag a relatively smooth appearance and a narrow white band may be present; Instar VI, all loose leaf pieces have been plastered and a broad white band occupies one-quarter of the bag length; Instar VII, similar to VI but with a broader white band (one-third of bag length) (*Figure 1* for some examples).

Wood (1966) estimated that the total duration of larval development in *M. plana* was 50–60 days, with 8 days spent on the first instar, 21 days on the second and 35 days on the third. The total development time was similar to those in our study, but the development of the second and third instars took 3–6 times longer. Such a difference may be explained by the lower nutrient content of foliage from seedlings compared with that from mature

palms.

Syed (1978) reported that total developmental times for male and female larvae were 80 and 113 days, respectively. These exceed the values obtained in this study by almost two-fold. The difference could not be explained by temperature because Syed used a similar temperature regime. He used *Cassia* sp. as the host plant and it is possible that the larvae took longer to develop on that host than on oil palm.

The feeding preference of most larvae of *M. plana* for the upper surface may be related to the surface texture of oil palm leaflets. The upper surface is relatively smooth but the lower surface is rough and covered with numerous short trichomes. These trichomes probably provide a better leaf surface for the larvae to adhere to during moulting. Levin (1973) reported that, in some plant species, trichomes produce alkaloids and phenolic compounds detrimental to herbivores. The presence of tannins in oil palm (Basri, 1993) may suggest that oil palm trichomes also produce phenolic compounds. It may also be possible that these trichomes act as mechanical barriers to herbivores (Pillemer and Tingley, 1976)). In relation to field control of *M. plana*, adequate spray coverage on the upper surface is therefore critical.

Wood (1966) reported that the duration of the male pupal stage varied from 21 to 28 days, but gave no mean values or sample sizes. His results were within the upper range of our findings, possibly because his larvae fed on seedlings instead of leaflets. As already suggested, seedlings may not be as nutritious as mature palms, resulting in slower development of the pupae.

Syed (1978) reported that mean pupal developmental time in a sample of nine male pupae was 26.8 days, 5.4 days longer than in our results. Such a longer duration was probably related to the use of a smaller sample size or the use of a different host plant, *Cassia* sp.

Wood (1966) and Syed (1978) did not report on pupal duration of the female. Our study demonstrates the presence of sexual dimorphism between the male and the female pupal periods. This phenomenon has not been reported in life history studies with other bagworm species such as *T. ephemeraeformis* (Kaufmann 1968), and *E. crameri* (Ameen and Sultana, 1977). It is possible that this aspect has been overlooked in these species because of the concealed nature of the pupae.

Our finding on the life span of the adult male (1–2 days) agrees with those of Wood (1966) on *M. plana* (1–2 days), Kaufmann (1968) on *T. ephemeraeformis* (1–2 days) and Ameen and Sultana (1977) on *E. crameri* (< 3 days). In the case of the adult female, a similar result to ours (7 days) was reported for *T.ephemeraeformis* (7 days) by Kaufmann (1968). From these few data, it would seem that adult psychids have generally short life spans.

The preponderance of males to females found in our study was a significant departure ($X^2 = 35.52$, df = 1, $p < 0.01$) from the 1:1 sex ratio commonly found in insect species (Thornhill and Alcock, 1983). This phenomenon has been reported in *E. crameri*, *H. huebneri* and *P. plagiophleps* whose respective ratios were 6:1, 2:1 and 2:1 (Heather, 1975; Ameen and Sultana, 1977; Howlader, 1990) and it is common among lepidopteran species (Cardé and Baker, 1984). Nevertheless, our current results need to be verified by both laboratory and field data because the destructive sampling of larvae, particularly of late instars, could have affected the ratio. There is also merit in studying the sex-ratio of field populations of *M. plana* because there is evidence, as reported for the sawfly, *Euura lasiolepsis* (Hymenoptera: Tenthredinidae) (Craig *et al.*, 1992), that host plant quality affects the sex ratio of herbivores. We could perhaps anticipate that bagworms feeding on different host plants would have different sex ratios.

Our study revealed that the developmental time from egg to adult was similar for both males and females. This was possible because although females had longer developmental time than males in the larval stage (by 11–13 days), their pupae are much simpler in morphology and hence females had a shorter pupal stage (11.4 days less than that of males). Such a differential developmental time for the larval and pupal stages may be common among other psychids; however, this has not been established. This phenomenon causes the emergence of adult males and females within generations to be synchronous; mating is therefore more likely to take place between adults from within the same generation. Such a reproductive synchrony appears possible in the field: Basri (unpublished data) found

that a field population of *M. plana* at PORIM Kluang exhibited generation cycles with a period of approximately one generation (*i.e.* 2.8 months) for four successive generations (*i.e.* between October 1989 and September 1990). It is recognized that reproductive asynchrony could still occur because it would be possible for the fastest individuals in one generation to emerge at the same time as the slowest individuals of the previous generation (*i.e.* within an overlapping period of 8 days). However, the probability of this occurring is low because the period of overlap is only about 9% of the generation time. Further, in general, overlapping generations can arise only if the adult stage has a great longevity, which is not so for the species we studied. Thus, once an outbreak is encountered it is important to follow the population changes in relation to the stages present, to ascertain when the population is expected to increase again, and time control measures if needed.

Syed (1978) suggested that overlapping generations were required for *M. plana* to increase in abundance because of the large difference in larval developmental time between males and females (about 30 days). However, our results contradict his suggestion because mating of individuals from the same generation could occur. Further, as indicated above, our results suggest that overlapping generations are less likely to cause an outbreak than are synchronous generations.

CONCLUSION

Our present study has added more information on the life history of *M. plana* and this will form a useful basis for further studies on its biology and ecology, and for pest management. Comparisons of findings with those of past workers have been difficult because earlier information is scanty. Nevertheless, we believe our results are more applicable to the oil palm because we have used the actual host plant in our investigation.

The controlled environment room we used provided conditions similar to the outside environment. Nevertheless, the results from laboratory rearing programmes should always be confirmed by field investigations.

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