RESEARCH ARTICLES

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EFFECTS OF TEMPERATURE ON THE DEVELOPMENT AND SURVIVAL OF THE BAGWORMS *Pteroma pendula* AND *Metisa plana* (Lepidoptera: Psychidae)

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ABSTRACT

The effects of temperature on the development and survival of Pteroma pendula *and* Metisa plana *was investigated over a range of temperatures in the laboratory.* Pteroma pendula *and* M. plana *were able to complete their life cycles at temperatures between 20°C-35°C but did not survive at 15°C and 40°C. The duration of life stages of* P. pendula *significantly decreased with increases in temperature with optimum survival of between 25°C and 30°C, while the highest was at 30°C. In the case of* M. plana*, except for survivorship of male pupae with five instars at 79% at 25°C, the optimum survivorship was around 30°C for all other life stages. The temperature threshold for* P. pendula *life stages was 11°C-18°C, while that of* M. plana *ranged from 2°C-16°C; when subdivided, a threshold of 2°C-8°C was recorded for the egg to adult stages and 9°C-16°C for the egg and larval stages. Thermal constant for* P. pendula *was 80.3°d, 443.0°d, 566.3°d, 47.5°d, 33.9°d for eggs, female larvae, male larvae, female pupae and male pupae, respectively. Overall egg to female and male adult emergence required 544.0°d and 761.3°d to complete. For* M. plana*, the readings were 555°d-1083°d for the larval stages, 69°d-200°d for eggs and pupae, while the egg to adult stages recorded the highest at 1440°d-2134°d. Both species recorded significantly highest temperature of 30°C for adult female weight, fecundity and* R^0 *with the most favourable values of T, DT,* r_c, r_m *and* λ *recorded at 35°C.*

Keywords: *M. plana*, population dynamics, *P. pendula*, temperature, thermal constant.

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INTRODUCTION

Weather plays an important role in the abundance and even outbreak of insect pests (Thomson *et al*., 1984; Martinat, 1997). Amongst the elements of weather, temperature is an important and widely studied climatic factor in insect bioclimatology (Messenger, 1976; Atkinson, 1999). Temperature affects rate of growth, development, activity and dispersal of insects (Andrewartha and Birch, 1954; Howe, 1967). In forest pests, *Hyphantria cunea* Drury and *Choristoneura occidentalis* Freeman, long-term field records associated outbreaks with warm summers (Morris, 1964; Thomson *et al*., 1984), but extremely high temperatures saw the collapse of *C. occidentalis* outbreaks.

For the bagworm *Thyridopteryx ephemeraeformis*, host plant species and bag size significantly affected the internal temperature of bags (Smith and Barrows, 1991) and internal bag temperatures were higher than ambient air (Barbosa *et al*., 1983). These higher temperatures resulted in shorter developmental time and enhanced reproductive

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potential and abundance.

Morris (1957) defined population dynamics as the measurement of population changes from generation to generation and the study of environmental factors responsible for the changes. This entails measuring the changes in the populations and determining the factors associated with them (Waters, 1969). There is no experimental data from the Southeast Asian region on the effect of temperature on bagworm population dynamics in oil palm. The role that temperature plays can only be surmised to be an important contributive factor in the observations of coincidence between outbreaks and dry weather (Syed and Shah, 1977; Basri *et al*., 1988; Hoong and Hoh, 1992; Siburat and Mojiun, 1998). Whatever information that is available is mostly in the form of short notes (Woods, 1968; Chung, 1990; Siburat and Mojiun, 1998) which do not provide sufficient details as to the influence of temperature on the development and survival (Basri, 1993). This article reports the effects of temperature on the development and survival of *P. pendula* and *M. plana*.

MATERIALS AND METHODS

The effects of temperature on the duration and survival of egg, larval and pupal stages, adult female weight and fecundity, and reproductive potential were examined at the Oil Palm Research Station laboratory, Banting, Selangor with the use of constant temperature cabinets set at 15°C, 20°C, 25°C, 35°C, and 40°C ± 1°C, 80 ± 5% RH and 12 hr photophase. Newly mated 20-30 females of *P. pendula* and *M. plana* were collected from marked field colonies, each being kept in a 500 ml clear plastic cup capped with 40-mesh wire gauze aperture at each constant temperature. Bags were observed daily until the eggs hatched. Mature and unlaid eggs could be seen through the translucent skin of the gravid female abdomen. The female lays its eggs in the pupal case together with hair-like scales within the bag. The duration of the egg stage for each temperature regime was recorded. The number of larvae that emerged was noted and bags were dissected to enumerate the number of eggs that were unfertilised and failed to hatch for calculation of percent survival. The data of pupae that were parasitised or suspected to be abnormal were discarded.

Visually normal hatchings from two of the above females for each species were reared at each temperature on leaflet segments in 500 ml clear plastic cups (Ho *et al*., 2010). Five larvae were reared on each leaflet segment, the latter being changed every three days. The duration and number of larvae at each instar were measured from head capsule width and the pupae were recorded for calculation of mean larval and pupal duration and % survival. The end of the pupal period was taken to be the start of calling by females and the eclosion of males. From these, the duration of egg to adult emergence and survival rate were obtained. Adult female survivorship was estimated by the sum of calling duration, average laboratory and field oviposition time (Ho *et al*., 2010) of 5.0 and 7.5 days for *P. pendula* and *M. plana*, respectively. Similarly, egg production was estimated by multiplying the number of eggs in dissected females at the end of calling by mean % fecundity in respect of total laid and unlaid eggs for the laboratory and field of 85.4% and 85.2% for *P. pendula* and *M. plana* respectively. Using the sex ratio of 1:1, the net reproductive rate (R_0, $\sum l_x m_x$), mean generation time (T in days, $\sum x l_x m_x / R_0$), intrinsic rate of population increase (r_m, obtained through iterative balancing $\sum e^{-rcx} x l_x m_x = 1$) and doubling time (DT in days, $[(\log_e 2)/r_c]$ were calculated. Prior to dissection, adult female weight (mg) was measured.

Further appraisal of the effect of temperature was carried out by plotting development period against temperature. Regression analysis was used to determine the relationship between temperature and the rate of development from birth to death. Based on this relationship, the elucidation of temperature thresholds (t°C) and the thermal constant K (°d) for the development of the various immature stages were determined (Campbell *et al*., 1974; Atkinson, 1999).

RESULTS

Head capsule measurements confirmed existence of four larval instars for both sexes in *P. pendula* which corresponded with Krishnan's (1977) report but contrasted with Syed's (1978) report of five. A sexual difference in the number of instars of *M. plana* of five to six for males and six to seven for females as reported by Basri and Kevan (1995) was reconfirmed in this study. All stages of *P. pendula* and *M. plana* did not survive at 15°C and 40°C (*Tables 1* and *3*). At 20°C, 25°C, 30°C and 35°C the duration of all life stages of both *P. pendula* and *M. plana* significantly decreased with increases in temperature. Except for *M. plana* whereby the survival of male pupae with five instars was 78.95% at 25°C, the highest survival rates for the remaining life stages were recorded at 30°C (*Figures 1* and *2*). In general, a severe decline in survival occurred at 35°C.

Significant r^2 values of near unity showed a relationship of the rate of development with temperature to be linear for the various life stages (*Tables 2* and *4*). This verified the data to be within the linear Region B of the typical development rate and constant temperature curve (Campbell

TABLE 1. DURATION (days) AND SURVIVAL OF EGG, LARVAL AND PUPAL STAGES OF *Pteroma pendula* AT DIFFERENT CONSTANT TEMPERATURES

Stages ($\bar{x}$ days ± S.E.)	Temperatures, (°C ± 1°C)					
	15	20	25	30	35	40
Eggs	0	14.13 ± 0.76a	8.10 ± 0.69b	5.92 ± 0.53c	3.79 ± 0.31d	0
(% survival)		43.62	53.49	79.08	45.08	
Larvae,♀(4 instars)	0	63.38 ± 4.54a	43.74 ± 0.75b	31.66 ± 0.96c	19.80 ± 1.33d	0
(% survival)		34.78	77.50	89.23	55.56	
Larvae, ♂(4 instars)	0	61.86 ± 3.18a	44.31 ± 0.91b	34.55 ± 0.89c	23.00 ± 1.79d	0
(% survival)		35.00	76.32	88.24	56.25	
Pupae, ♀	0	10.00 ± 1.06a	6.00 ± 0.28b	3.67 ± 0.17c	2.40 ± 0.27d	0
(% survival)		62.50	83.87	89.66	50.00	
Pupae, ♂	0	9.50 ± 0.84a	5.92 ± 0.30b	3.38 ± 0.15c	1.83 ± 0.44d	0
(% survival)		85.71	86.21	88.33	66.67	
Egg to adult ♀ emergence	0	89.00 ± 6.03a	60.54 ± 0.94b	43.29 ± 1.06c	25.20 ± 2.25d	0
Egg to adult ♂ emergence	0	83.33 ± 3.70a	61.24 ± 1.05b	45.72 ± 0.96c	31.17 ± 1.37d	0
Egg to adult survival rate (%)	0	10.68	31.48	62.50	13.41	0

Note: Means within rows for each species followed by the same letter are not significantly different at p=0.05 using one-way ANOVA and LSD.

TABLE 2. TEMPERATURE THRESHOLDS AND THERMAL CONSTANTS FOR THE DEVELOPMENT OF *Pteroma pendula*

Developmental stages	Linear equation*	r^2	Temperature threshold (°C)	Thermal constant, K (°d)
Eggs	Y = -0.186 + 0.012T	0.97	14.91	80.29
Larvae, ♀	Y = -0.032 + 0.002T	0.94	14.13	443.03
Larvae, ♂	Y = -0.021 + 0.002T	0.95	11.77	566.26
Pupae, ♀	Y = -0.341 + 0.021T	0.96	16.19	47.46
Pupae, ♂	Y = -0.530 + 0.030T	0.92	17.97	33.89
Egg to adult ♀ emergence	Y = -0.028 + 0.002T	0.92	15.19	544.04
Egg to adult ♂ emergence	Y = -0.016 + 0.001T	0.96	11.84	761.25

Note: * Y = 1/Day; T = temperature (°C).

et al., 1974; Allsopp *et al*., 1991). From this, the temperature threshold and thermal constant were calculated by solving the linear equation for Y = 1/Day = 0 and taking the reciprocal of the gradient of the linear regression equation respectively. These returned temperature thresholds for *P. pendula* life stages of 11°C-18°C, while that of *M. plana* ranged from 2°C-16°C, which in turn could be subdivided into 9°C-16°C for the egg and larval stages and 2°C-8°C for the egg to adult stages. Thermal constant for *P. pendula* was 80.3°d, 443.0°d, 566.3°d, 47.5°d, 33.9°d for eggs, female larvae, male larvae, female pupae and male pupae, respectively. Overall egg to female and male adult emergence required 544.0°d and 761.3°d to complete. For *M. plana*, the readings were generally higher for the larval (557.9°d-1083°d) than the egg (199.8°d) and pupal stages (68.6°d-128.7°d) with the highest being for the egg to adult emergence at 1439.7°d-2133.8°d.

Both species of bagworm recorded a significantly higher temperature of 30°C for adult female weight, fecundity and R_0 (*Table 5*). Most favourable values of T, DT, capacity of population increase (r_c, $[\log_e(R_0)]/T$), r_m and finite rate of population increase (λ, e^{rm}) were recorded at 35°C.

TABLE 3. DURATION (days) AND SURVIVAL OF EGG, LARVAL AND PUPAL STAGES OF *Metisa plana* AT DIFFERENT CONSTANT TEMPERATURES

Developmental stages ($\bar{x}$ days ± S.E.)	Temperatures, (°C ± 1°C)					
	15	20	25	30	35	40
Eggs (% survival)	0	22.30 ± 0.55a 28.65	18.20 ± 0.66b 33.98	10.27 ± 0.63c 85.22	8.75 ± 0.72d 64.54	0
Larvae, ♀ (7 instars) (% survival)	0	90.80 ± 3.42a 16.13	74.11 ± 1.39b 73.47	57.11 ± 0.77c 96.51	39.93 ± 0.94d 64.79	0
Larvae, ♀ (6 instars) (% survival)	0	78.67 ± 11.50a 27.27	67.62 ± 2.11b 84.00	50.37 ± 0.85c 88.52	33.35 ± 0.63d 50.00	0
Larvae, ♂ (6 instars) (% survival)	0	71.50 ± 6.40a 28.57	63.47 ± 1.91b 79.17	49.30 ± 0.86c 83.02	28.58 ± 1.38d 48.98	0
Larvae, ♂ (5 instars) (% survival)	0	63.33 ± 3.19a 10.71	56.95 ± 1.01b 76.00	41.39 ± 0.59c 94.68	23.00 ± 0.45d 55.32	0
Pupae, ♀ (7 instars) (% survival)	0	14.00 ± 1.87a 60.00	9.72 ± 0.60b 77.78	5.30 ± 0.21c 80.72	3.53 ± 0.37d 65.22	0
Pupae, ♀ (6 instars) (% survival)	0	11.00 ± 0.00a 33.33	8.86 ± 1.00a 38.10	5.67 ± 0.26b 66.67	4.18 ± 0.55c 65.38	0
Pupae, ♂ (6 instars) (% survival)	0	20.00 ± 1.41a 50.00	14.08 ± 0.97b 63.16	9.88 ± 0.48c 93.18	5.91 ± 0.42d 91.67	0
Pupae, ♂ (5 instars) (% survival)	0	21.50 ± 0.71a 66.67	12.73 ± 0.51b 78.95	8.71 ± 0.44c 70.79	5.96 ± 0.37d 53.85	0
Egg to adult ♀ emergence (7 instars)	0	123.67 ± 5.76a	104.75 ± 1.79b	84.88 ± 0.87c	66.00 ± 1.27d	0
Egg to adult ♀ emergence (6 instars)	0	106.00 ± 0.00a	92.63 ± 3.01b	79.06 ± 0.95c	59.47 ± 0.87d	0
Egg to adult ♂ emergence (6 instars)	0	108.50 ± 14.85a	99.67 ± 1.76b	80.76 ± 1.02c	56.50 ± 1.45d	0
Egg to adult ♂ emergence (5 instars)	0	109.00 ± 4.24a	91.70 ± 1.18b	72.13 ± 0.84c	50.64 ± 0.56d	0
Egg to adult survival rate (%)	0	2.53	19.70	59.83	37.74	0

Note: Means within rows for each species followed by the same letter are not significantly different at p=0.05 using one-way ANOVA and LSD.

DISCUSSION

Both bagworm species showed the general trend of insects to have shorter developmental times with increasing temperatures until the optimum was reached (Assante *et al*., 1991; Dent, 1997). The shortest developmental times were consistently recoded for all life stages at 35°C whilst greatest survivorship was at 30°C in the majority of cases. The former was supported by or resulted in the most demographic statistics being recorded at this temperature whilst greatest adult female weight and fecundity, as a reflection of increased bagworm reproductive potential (Rhainds *et al*., 1995a,b,c; Rhainds, 1999) supported the latter. Thus, optimum performance of *P. pendula* and its survival could be expected to occur in the range of 25°C-30°C (*Figure 1*) and this is shown clearly by the trend of egg to becoming an adult. While for *M. plana*, the optimum was around 30°C and slanted towards 35°C as displayed by the trend of egg to adult (*Figure 2*). The relatively high percentage of egg to adult for these two bagworm species at their respective optimum temperature ranges indicates a phenomenal potential of escalation in population and hence a potential threat on their major host plant, the oil palm.

TABLE 4. TEMPERATURE THRESHOLDS AND THERMAL CONSTANTS FOR THE DEVELOPMENT OF *Metisa plana*

Stages	Linear equation*	r^2	Temperature threshold (°C)	Thermal constant, K (°d)
Eggs	Y = -0.060 + 0.005T	0.95	11.94	199.75
Larvae, ♀ (7 instars)	Y = -0.009 + 0.001T	0.94	9.34	1083.04
Larvae, ♀ (6 instars)	Y = -0.012 + 0.001T	0.91	10.54	876.90
Larvae, ♂ (6 instars)	Y = -0.016 + 0.001T	0.84	11.76	741.04
Larvae, ♂ (5 instars)	Y = -0.024 + 0.002T	0.83	13.41	557.90
Pupae, ♀ (7 instars)	Y = -0.238 + 0.015T	0.96	16.36	68.64
Pupae, ♀ (6 instars)	Y = -0.123 + 0.010T	0.96	12.22	99.08
Pupae, ♂ (6 instars)	Y = -0.0116 + 0.008T	0.93	14.91	128.68
Pupae, ♂ (5 instars)	Y = -0.0116 + 0.008T	0.99	14.68	126.05
Egg to adult ♀ emergence (7 instars)	Y = -0.002 + 0.0004T	0.97	3.73	2 133.80
Egg to adult ♀ emergence (6 instars)	Y = -0.001 + 0.0004T	0.93	1.58	2 086.69
Egg to adult ♂ emergence (6 instars)	Y = -0.003 + 0.0006T	0.88	5.32	1 798.97
Egg to adult ♂ emergence (5 instars)	Y = -0.006 + 0.001T	0.93	8.17	1 439.67

Note: * Y = 1/Day; T = temperature (°C).

TABLE 5. EFFECT OF TEMPERATURE ON ADULT FEMALE WEIGHT, FECUNDITY AND DEMOGRAPHIC STATISTICS OF *Pteroma pendula* AND *Metisa plana*

Parameter	Temperature (°C)			
	20	25	30	35
Pteroma pendula:				
Adult ♀ weight ($\bar{x}$ mg ± S.E.)	3.00 ± 0.35a	5.58 ± 0.36b	7.65 ± 0.24c	5.60 ± 1.15b
Estimated fecundity ($\bar{x}$ No. eggs ± S.E.)	38.60 ± 2.82a	56.00 ± 2.60b	83.13 ± 1.07c	66.27 ± 4.64d
R^0	19.30	28.00	41.57	33.14
T	93.39	65.06	46.63	29.34
DT	21.87	13.53	8.67	5.81
r_c	0.0317	0.0512	0.0794	0.1193
r_m	0.0317	0.0512	0.0800	0.1194
λ	1.0322	1.0526	1.0833	1.126
Metisa plana:				
Adult ♀ weight ($\bar{x}$ mg ± S.E.)	22.75 ± 2.18a	24.86 ± 0.60a	34.69 ± 0.62b	26.38 ± 0.77a
Estimated fecundity ($\bar{x}$ No. eggs ± S.E.)	53.68 ± 12.19a	100.61 ± 3.60b	153.23 ± 1.44c	133.95 ± 2.61d
R_0	26.84	50.30	76.61	66.97
T	125.93	109.48	89.52	70.52
DT	26.53	19.37	14.30	11.63
r_c	0.0261	0.0358	0.0485	0.0596
r_m	0.0263	0.0359	0.0486	0.0599
λ	1.0267	1.0366	1.0498	1.0618

Note: Means for female weight and fecundity for each species followed by the same letter are not significantly different at p=0.05 using one-way ANOVA and LSD.

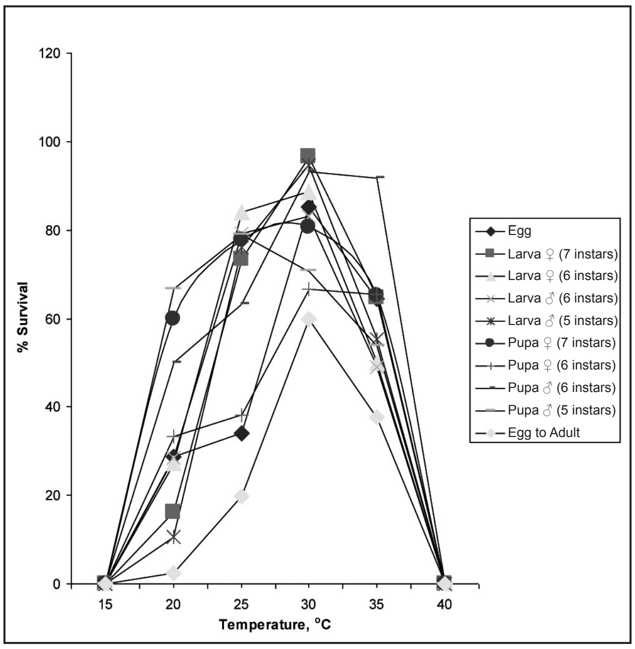

Figure 1. Various stages of development of Pteroma pendula *at varying constant temperatures.*

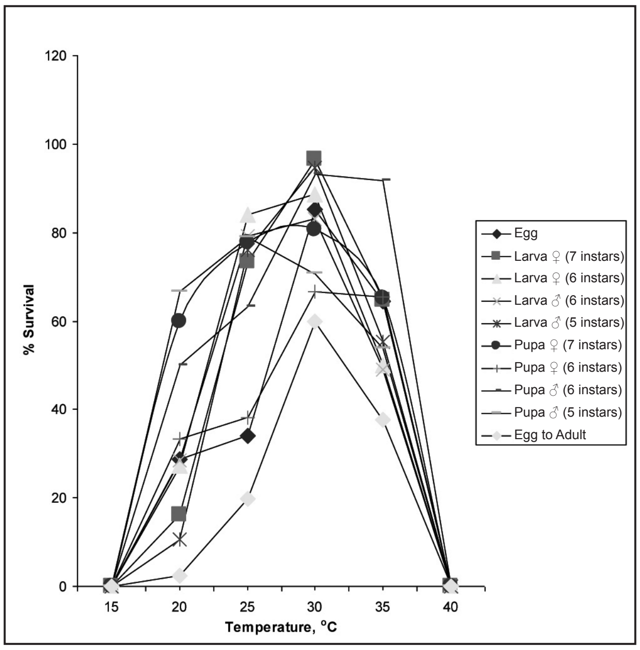

Figure 2. Various stages of development of Metisa plana *at varying constant temperatures.*

The temperature threshold of 11°C-18°C and 2°C-16°C for *P. pendula* and *M. plana*, respectively were near to or lower than the experimental lower survival limit of 15°C. This indication, however, may be only of theoretical value of Malaysia (Gray, 1969). Thermal constant of 33.89-761.25°d of *P. pendula* was lower than the 68.64-2133.80°d for *M. plana*. This could be a reflection of the variable number of instars of *M. plana* and fewer larval stages of *P. pendula*. Nevertheless, a lower energy requirement for all developmental stages and the completion of *P. pendula* life cycle was indicated. This could be translated into greater success of the species than *M. plana* under lower temperature situations like periods of sustained wet weather, and this could initiate a population outbreak upon an inception of a dry and warmer period.

Changes in the populations of both species of bagworms could either be due to fecundity, mortality or both, and under the controlled constant temperatures the interaction of fecundity and mortality could certainly determine survivorship and influence the population dynamics. In general, even though the estimated fecundity and the net reproductive rate (R_0) for *M. plana* were superior than *P. pendula*, the values of r_m and λ were higher for *P. pendula* than *M. plana* for all temperatures, thus the reproductive capacity is higher for the former. Coupling this with a comparatively shorter mean generation time (T) of 47 days, a faster doubling time (DT) of nine days at a lower optimal thermal constant, *P. pendula* is indicated to be more competitive than *M. plana* (T=90 days; DT=14 days) over the range of temperatures tested and thus this has the potential of a rapid population growth, hence more likelihood to initiate a population outbreak.

The use of constant temperatures to evaluate responses of insects to climate has been criticised by many researchers due to the fact that the thermal hygral habitat fluctuates in 24 hr cycles for most terrestrial insect species (Messenger and Flitters, 1959). Sidiqui and Barlow (1973), Foley (1981) and Taylor and Shields (1990) have shown insects to develop faster under such conditions. Campbell *et al*. (1974) nevertheless suggested fair reflection of constant temperature data with that of the field if the former lies within the linear zone of the development rate-temperature curve. Data of the present study fulfilled this condition (*Tables 2* and *4*) where consistently high r^2 values were recorded for all developmental stages. Notwithstanding this, and without experimentation to show otherwise, it is best to use the present results within its experimental limitations, *i.e.* the comparison of responses of *P. pendula* and *M. plana* under said laboratory temperature regimes. Results from this study have provided essential fundamental information in understanding the behaviour of both pest species and also in formulating future control strategies.

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