ASSESSMENT ON VORACITY AND PREDATION BY PREDATOR, *Sycanus dichotomus* STAL. (Hemiptera: Reduviidae) TO OIL PALM BAGWORM, *Pteroma pendula*

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ABSTRACT

Sycanus dichotomus *Stal. (Hemiptera: Reduviidae) is a generalist predator with a wide prey spectrum that commonly preys on bagworms and nettle caterpillars in oil palm plantations in Malaysia. The voracity of fifth instar nymphs and adults (males and females) of* S. dichotomus *using* Pteroma pendula *Joannis (Lepidoptera: Psychidae) third instar larvae as prey was evaluated in the laboratory, as well as its relationship with the development stage and exposure time on the voracity and predation rate. The number of preys consumed by predators was recorded at every 3, 24 and 48 hr intervals. The maximum voracity and predation rates were always greater in adults. The adult females displayed the highest prey consumption (1.0- 4.33 bagworms) followed by adult males (0.67-4.17 bagworms), and fifth instar nymphs (0.5-3.0 bagworms) at all time intervals. Although the fifth instar nymphs were able to kill the prey offered, the differences in predation potential indicated that the adult males and females were more vigorous and voracious in capturing and killing prey compared to the fifth instar nymphs. Results showed that the overall effect of the developmental stages of* S. dichotomus *on voracity and predation rate was highly significant (F = 10.420; df = 2; P <0.001). Similarly, the time intervals also exhibited a highly significant effect on the voracity and predation rate of* S. dichotomus *(F = 95.267; df = 2; P <0.001). However, the relationship between the predator developmental stages and exposure times was not significant (F = 2.444; df = 4; P = 0.300). This finding indicates the potential of the adults' stage of* S. dichotomus *to be released in the field, aiming for greater bagworm reduction in subsequent generation. In future research, it is necessary to assess the dynamic features of prey-predator system in an actual oil palm field.*

INTRODUCTION

Awareness in biological control has increased considerably in response to the various effects of pesticides on the environment. Biological control favours conservation, and the sustainable use of biological resources such as natural enemies of insects (Isaacs *et al.*, 2009; Mazza *et al.*, 2014;

Karamaouna *et al.*, 2019). Symondson *et al.* (2002) summarised that the assemblages of generalist predators significantly reduced pest abundance up to 79%, decreasing a 65% loss to crops. On the other hand, study by Karamaouna *et al.* (2019) discovered the potential of ground cover with mixtures of selected plants as habitats for beneficial arthropods in an olive grove.

In Malaysia, oil palm is an important crop commodity which covers 5.81 million hectares of plantation area, in which the average of fresh fruit bunches (FFB) yield had increased to 17.16 t ha^{-1} yr^{-1}

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in 2018 (Kushairi *et al.*, 2019). Agriculture through large scale mono-cropping deliberately introduces alterations in the environment, exposing the crop to serious attacks of pests and diseases. When there is a breakdown in natural control, pest numbers might increase, and that can lead to a significant outbreak. Bagworms (*Metisa plana*, *Pteroma pendula* and *Mahasena corbetti*) and nettle caterpillars (*Darna* sp. and *Setora nitens*) are the most prevalent insect pests of the oil palm plantation in Malaysia (Norman *et al.*, 2017). These bagworm species regularly damage oil palm leaves, leading to serious crop losses (Norman and Basri, 2007). Wood *et al.* (1973) reported that a 50% defoliation of the upper fronds by the bagworms had resulted in a yield loss of 43%. Biological control methods are favoured to reduce bagworms and nettle caterpillars population, including the planting of beneficial plants for sustaining the parasitoids and predators (Basri *et al.*, 1999; Wilcove and Koh 2010); pheromone trapping and spraying of bio-insecticide (Najib *et al.,* 2017); and implementation of an integrated pest management system (Mazmira *et al.*, 2015).

Predatory insects were proven to be effective biological control agents that provide an alternative to chemical dependence in agricultural systems (Jamian *et al.*, 2017). The assassin bugs (Hemiptera: Reduviidae) are an important group of predators found in oil palm plantations (De Chenon *et al.*, 1989). Among them, *Sycanus dichotomus* Stal. is the most common reduviid bug that feeds on nettle caterpillars such as *Darna* sp. and *Setothosea asigna* (De Chenon *et al.*, 2017; Singh, 1992); and bagworms such as *M. plana* and *P. pendula* (Norman *et al.*, 2017; Jamian *et al.,* 2010). Previous studies had shown that reduviid predators were suitable biological control agents for nymphs and larvae of insect pests (Schaefer and Ahmad, 1987; Zulkefli *et al.,* 2004; Siti Nurulhidayah and Norman, 2016; Jamian *et al.*, 2017). *Sycanus collaris* had been successfully released as an important natural enemy to manage *Helopeltis* sp. and leaf roller caterpillars in forest plantations in Sumatra, Indonesia (Budi *et al.*, 2008). De Chenon *et al.* (1989) proved the successful use of *S. dichotomus* as a biocontrol agent for *M. plana* where an adult *S. dichotomus* would be able to consume an average of 430 young larvae of *M. plana* during its life-span. In Malaysia, a semi-field study conducted by Jamian and Nur Azura (2018) revealed that the maintenance of *S. dichotomus* population was eased by integration with beneficial plants. In an oil palm plantation, insect pests such as bagworms are commonly found feeding on an entire palm foliage. The possible usage of this predator as an effective biological control agent against oil palm insect pests such as bagworms was also identified in the study.

The balance ratio between the occurrence of predator and bagworm infestation is important for an integrated pest management (IPM) of the pest. The development of mass-rearing techniques is aimed at producing large numbers of healthy natural enemies of good quality. The right stage and timing are also crucial when releasing them in the field. Thus, this study was conducted to evaluate the voracity and predation rate of fifth instar nymphs and adults (males and females) of *S. dichotomus* using third instar *P. pendula* larvae as preys, as well as to evaluate its relationship with the development stage and exposure time in relation to predation efficiency. The results may be useful for understanding the predator's population dynamics in the field in relation to the availability of natural prey species.

MATERIALS AND METHODS

Environmental Conditions

The study was conducted at the Entomology Laboratory, Malaysian Palm Oil Board (MPOB), Bandar Baru Bangi, Selangor, Malaysia (2°58'07.5"N and 101°44'31.8"E). All insect rearing and experiments were carried out in an environmentally controlled room at day temperature of 27±1°C, night temperature of 24±1°C, a photoperiod of 12:12 (L:D) hour and 50%-70% relative humidity, monitored with a hygrothermograph (Dickson brand).

Insects' Rearing

A culture of *S. dichotomus* was established in the laboratory using specimens originating from a field collection in Tapah and Teluk Intan, Perak, Malaysia. The adults were paired and caged in a transparent cylinder cage (12.5 cm diameter x 23.5 cm height) with a ventilated lid. Small ferns and oil palm leaflets were provided in the rearing cage to mimic their concealed microhabitat and for egg laying. All development stages of the predator were fed on alternative prey larvae such as mealworm, *Tenebrio molitor* and rice moth, *Corcyra cephalonica*. However, twice a month they were provided with bagworm larvae. Mixed prey larvae were provided to supply a more broadened group of nutrients to the predator. Diluted honey solution was also provided daily as the food source. The predators were reared in small batches in the rearing cages. The rearing of the *S. dichotomus* was carried out based on methods utilised by Siti Nurulhidayah and Norman (2016). Individuals (fifth instar nymphs, adult males and adult females) produced in this rearing system were used for the experiments (*Figure 1*). The rationalisation of the selection of these stages is due to the aim of having them released in the oil palm plantation in order to warrant optimum predator size for maximum predation rate. During the rearing process, it was observed that the final instar nymphs (fifth instar, with a mean body length
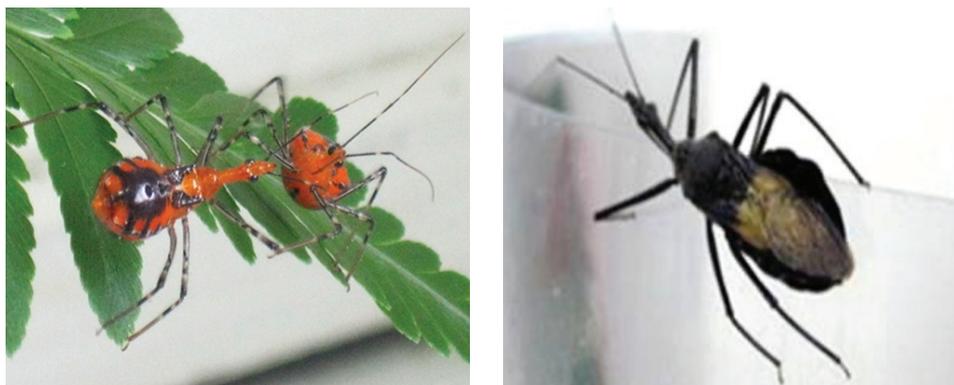
Figure 1. The fifth instar nymphs (left) and adult stage (right) of S. dichotomus.

of 22.3 ± 0.517 mm) were the most voracious among the other nymphal instars, particularly when fed with bagworms (Siti Nurulhidayah, unpublished).

Voracity and Prey Consumption

Prior to the experiments, fifth instar nymphs, adult males and adult females were held in separate cages and *ad libitum*-fed with the larvae of bagworm *Pteroma pendula*. Nymphs were maintained under these conditions for 24 hr after moulting to the fifth instar - similarly with the adults after their emergence, without any prey prior to the experiment. Only moistened honey cotton was offered in a Petri dish that was replenished daily. Adult males and females can be distinguished by their body and abdominal sizes with the males being smaller. The purpose of using newly moulted predator was to standardise the age of the predator for fair observations. Any predator's nymph that moulted during the experiments might affect the feeding rates (Fantinou *et al.*, 2009).

Pteroma pendula larvae were collected from the infested oil palm plantation in Teluk Intan, Perak and maintained in the laboratory at day temperature of 27±1°C, night temperature of 24±1°C, a photoperiod of 12:12 (L:D) hour and 50%-70% relative humidity. A total of 10 third instar larvae of *P. pendula* were offered in order to evaluate the predation rate. The third instar *P. pendula* larvae were selected to ensure an intermediate size for maximum prey consumption by the predator. Ten *P. pendula* larvae were placed gently on oil palm leaf cutting (20 cm long) as their food and left in an experimental cage (12.5 cm diameter x 23.5 cm height). The bagworms were left undisturbed for 1 hr to settle. At the beginning of the test, the individual 24 hr-starved fifth instar nymph of *S. dichotomus* was introduced from the rearing cage to the experimental cage containing *P. pendula*. The moistened honey cotton was also offered in a Petri dish. The similar procedure was repeated to adult males and females. Ten replicates for each treatment were performed. Control treatment was performed with the same prey numbers in the absence of the predators. At 3, 24 and 48 hr after the start of the experiment, the interaction and predation activities were determined by the numbers of live and preyed bagworms in each experimental cage. These time intervals were chosen to measure the voracity of *S. dichotomus*. Dead preys were replaced daily to keep the prey density constant throughout the experiment.

Statistical Analyses

Determination of the voracity and prey consumption rate among fifth instar nymphs, adult males and adult females of *S. dichotomus* with a consistent number of preys given within exposure times were analysed using one-way analysis of variance (ANOVA), where the F test indicated a significant difference among different treatments means. Least Significant Difference (LSD) test at $P<0.05$ was used to determine difference in the mean. Interaction between the development stages of predators and exposure times was analysed using two-way ANOVA. Comparisons among means were conducted using all pairwise multiple comparison procedures (Holm-Sidak method) of significance test at 5% levels (SigmaPlot version 12.5).

RESULTS AND DISCUSSION

The predation activity of *S. dichotomus* towards *P. pendula* was observed in individual experimental cages in the laboratory. The study of the predation rates, as well as interaction between different developmental stages of predator and exposure time intervals allows the evaluation of the voracity and predation assessment of *S. dichotomus*.

Within the first 3 hr of the observation, there was no significant difference on the voracity or prey consumption among the fifth instar nymphs, adult males and adult females (*Figure 2*). Among the developmental stages/gender, it was observed that there was a significant difference on the mean

number of preys consumed between fifth instar nymphs and females after 24 hr of exposure (*Figure 2*). After 48 hr of exposure, it was found that both adult genders recorded significant differences with fifth instar nymphs in prey consumption. No significant difference was observed between males and females in their prey consumption or voracity during first 3 hr of exposure, as presented in *Table 1*. It is noteworthy that voracity of females and males did not differ. The number of unconsumed preys was generally kept at low levels and did not differ significantly among developmental stages/gender and exposure time intervals. For all exposure time intervals, it was recorded that the fifth instar nymphs consumed the least number of bagworms. The adult males consumed most, followed by the adult females. It was also recorded that predation efficiency increased as *S. dichotomus* developed from fifth instar to the adult. The relatively highest number of preys was consumed by adult females; 1.0 ± 0.258, 2.33 ± 0.211 and 4.33 ± 0.211 for 3, 24 and 48 hr, respectively (*Table 1*).

The experiment demonstrated that the voracity and prey consumption of the adult females were higher compared to the males and fifth instar nymphs. In general, the maximum predation rate values were always greater for both adult genders of *S. dichotomus*. Consequently, differences in predation rate, attack rate and handling time also indicate that the adults were more vigorous and voracious in capturing and killing prey compared to the fifth instar nymphs. A similar finding was recorded by Milonas *et al.* (2011). Furthermore, higher attack rate and shorter handling time in adults, particularly the females, indicate that the adult females are the most voracious stage. This condition verifies that the fifth instar nymphs had a lower predation rate based on the number of preys consumed. This might be due to their lower attack rates and longer prey handling time, as suggested by Milonas *et al.* (2011).

Results of the two-way ANOVA showed that the overall effect of developmental stages of *S. dichotomus* on voracity and predation rate was highly significant ($F = 10.420$; $df = 2$; $P < 0.001$). A similar finding was reported by Santos *et al.* (2016). They revealed that the success of a predator depends on behavioural characteristics, which can be affected by many factors, including the

TABLE 1. VORACITY (mean number of preys consumed ± standards error) OF *P. pendula* LARVAE CONSUMED BY *S. dichotomus* FOR DIFFERENT EXPOSURE TIME INTERVALS

Exposure time (hr)	Voracity ± standard error			ANOVA
	Fifth instar nymphs	Adult males	Adult females	
3	0.5 ± 0.224	0.67 ± 0.211	1.0 ± 0.258	n.s.
24	1.0 ± 0.258	1.5 ± 0.428	2.33 ± 0.211	*
48	3.0 ± 0.365	4.17 ± 0.307	4.33 ± 0.211	*

Note: ANOVA - analysis of variance. n.s. - not significant. *Significant at P<0.05 within the same row.
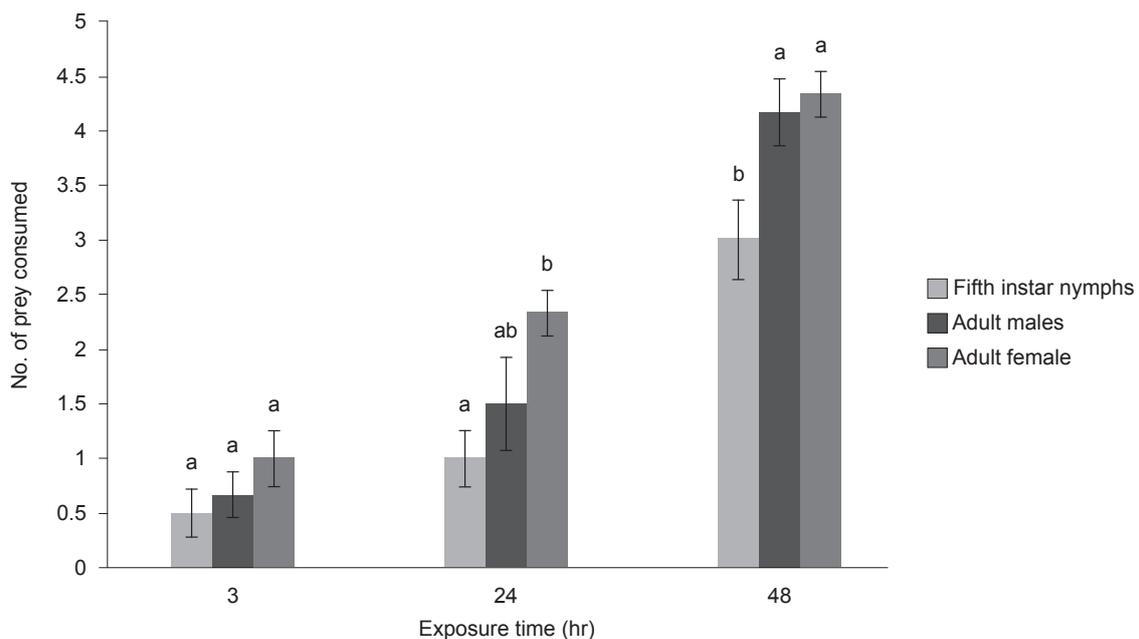
Figure 2. Mean (± standard error) prey consumption by fifth instar nymphs, adult males and adult females of S. dichotomus *showed by different exposure times. Means within each exposure time followed by different letters indicate significant differences between them (Least Significant Difference test; P < 0.05).*

TABLE 2. TWO-WAY ANALYSIS OF VARIANCE (ANOVA) ON THE PROPORTION OF PREY CONSUMED BY DIFFERENT DEVELOPMENT STAGES OF *S. dichotomus* IN RELATION TO EXPOSURE TIMES

Parameter	DF	SS	MS	F	P
Development stage	2	10.111	5.056	10.420	<0.001
Exposure time	2	92.444	46.222	95.267	<0.001
Development stage x exposure time	4	2.444	0.611	1.260	0.300

Note: DF - degree of freedom.
　　　SS - sum of squares.
　　　MS - mean squares.
　　　F - F-value.
　　　P- P-value.

predator's developmental stage. Similarly, the time intervals also exhibited a highly significant effect on the voracity and predation rate of *S. dichotomus* (F = 95.267; df = 2; P <0.001). However, the interaction of predator developmental stages and exposure times was not significant (F = 2.444; df = 4; P = 0.300) as shown in *Table 2*.

The *P. pendula* third instar larvae offered were approximately the same in terms of developmental stage, size and mobility. These factors may account for their acceptance by *S. dichotomus,* which could be explained through the functional response model that incorporated both predator and prey size (Aljetlawi *et al.*, 2004). Other factors, such as the long-term mass-rearing of the predator and the nutritional value of the prey may have influenced the results. Changes in predation behaviour associated with the age or stage of the predator have been well documented among invertebrates, including insects (McKemey *et al.*, 2003; Troost *et al.*, 2008). It has also been reported that the mean prey size increases with the body size of the predator (McArdle and Lawton, 1979; Cisneros and Rosenheim, 1997).

Based from observations during the experiment, *S. dichotomus* had attacked the bagworm larvae by penetrating its rostrum inside the anterior part of the bagworm (*Figure 3*). After the penetration, the predator remained motionless for a few minutes until the larvae stopped moving. The predator was inactive during feeding except when disturbed. This would last for several minutes to over an hour, as stated by Green (1973). The bagworms were entirely consumed by the predator and only their skin remained. This was observed after the dissection of the bagworm bag (*Figure 4*). This condition can be related with observations recorded by Ables (1978), that reduviid predators generally prefer lepidopteran caterpillars due to their soft cuticle and slow movement. In few cases, it was also observed that *S. dichotomus* would occasionally abandon a prey item that had already been killed during the experiment. This feeding behaviour, in which killed preys are either abandoned or left partially unconsumed has also been recorded in other predator studies (Lang and Gsödl, 2003; Fantinou *et al.*, 2009).

While conducting the predation test, it was revealed that during the prey search and attack, the voracity differs between the sexes. As previously hypothesised by Lucas *et al*. (1997) and Evans and Gunther (2005), adult females are usually more voracious than males owing to their larger size and high requirements of nutrients for egg production and oviposition. However, under such conditions and due to the smaller size of the males, it was convenient for them to catch smaller preys although larger ones offer higher energetic gain, since capture success generally decreases with increasing prey size (Hassell *et al.*, 1976; Roger *et al.*, 2000; Soares *et al.*, 2004). In addition, previous studies also show that food quality might affect the survival of several predators (Isikber and Copland, 2002; Kalushkov and Hodek, 2004), as well as the reproductive performance of the adults.

Figure 3. The predator attacked the bagworm larvae by penetrating its rostrum inside the anterior part of the bagworm.

Figure 4. Bagworm that was entirely consumed by the predator was left with only its skin remained.

CONCLUSION

Equal proportions of *P. pendula* instar larvae offered towards *S. dichotomus* showed a differential predation pattern with the greatest predation occurrence by the adults, particularly females. Overall, the results indicated that the adults *S. dichotomus* were more vigorous and voracious in consuming *P. pendula* instar larvae compared to the fifth instar nymph under controlled conditions. Although the relationship between the predator developmental stages and exposure times was not significant, this study revealed that predatory behaviour was influenced by the body mass and gender. The body mass and sex ratios of the adults might vary depending on the food source given during the rearing process (Siti Nurulhidayah and Norman, 2016). This finding may compensate the biological control of bagworms in oil palm crops. It also suggests that with better strategy according to its voracity capacity, increased level of control can be achieved. Regarding the higher voracity of the adults on *P. pendula*, it somehow suggests that this predator can be a useful biological control agent. An estimated maximum predation rate can be used to define optimal number of individual predators released in order to suppress prey in the field. The results of the present study indicate that the predator's developmental stage and foraging strategy might be components of a dynamic prey-predator system that needs more research and understanding. Further experiments on the influence of the environmental factors on the predator population in the field are required in order to clarify the voracity level of *S. dichotomus* on natural preys, as well as their availability on the predator's food preference. Therefore, prey preference of *S. dichotomus* towards *P. pendula* or other bagworm species in the field needs further investigation before the control efficacy of this predator against these prevalent oil palm insect pests can be fully determined. Furthermore, factors such as abiotic factors, prey availability, prey type and plant host may act simultaneously under the actual field conditions. Thus, the promising results of this study warrant further investigation on the possibility of using *S. dichotomus* or other species of the same family for practical control of oil palm insect pests. Mass production of these predators may be feasible at a relatively low cost, suggesting the possibility of releasing them periodically for insect pest control especially in oil palm plantations.

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