Journal of Oil Palm Research
DOI: https://doi.org/10.21894/jopr.2023.0017

THE INFLUENCE OF FLOWERING BENEFICIAL PLANT, *Turnera subulata* ON THE INSECT NATURAL ENEMIES' ABUNDANCE IN RELATION TO OIL PALM BAGWORM OCCURRENCE IN BAGAN DATUK, PERAK, MALAYSIA

SITI NURULHIDAYAH AHMAD[1]*; SAHARUL ABILLAH MOHAMAD[1]; OTHMAN ARSHAD[1] and MOHAMED MAZMIRA MOHD MASRI[1]

ABSTRACT

The devastating infestation of bagworms in Malaysia had significant impact on oil palm production. The influence of beneficial plant, Turnera subulata *on the natural enemies' abundance in relation to bagworm,* Pteroma pendula *occurrence in an oil palm plantation located in Bagan Datuk, Perak was investigated. Sampling techniques (yellow sticky trap and sweep net) were employed in each of the sampling areas: (i)* T. subulata *groves, and (ii) oil palm inter-row. A total of 1035 individuals of insect natural enemies representing four orders and nine families were collected. The highest diversity was found in the* T. subulata *groves, with Shannon-Wiener index (H') of 1.747 compared to inter-rows (1.447). These values are supported by the higher abundance of natural enemies on* T. subulata *groves that indicated 82% of total individuals captured, dominated by Chalchidae (580 individuals). Overall, the interaction between the techniques and locations was significant (F = 9.125; df = 1;* P *= 0.003). A significant positive correlation was observed between natural enemies and pupal stage of* P. pendula *(r = 0.659; r^2 = 0.434;* P *<0.001). The findings from this study suggest that the propagation of insect natural enemies can be effectively achieved by the establishment of beneficial plants such as* T. subulata*.*

Keywords: bagworm, beneficial plant, natural enemies, oil palm.

Received: 26 October 2022; **Accepted:** 16 March 2023; **Published online:** 13 April 2023.

INTRODUCTION

Numerous pests threaten crops throughout the world, imposing significant economic losses in the case of a lack of effective control. It is also important to note that using chemical pesticides to manage pests frequently fails to offer effective conventional control and causes serious environmental harm (Wood and Norman, 2019; Ziolkowska *et al*., 2021). For instance, excessive pesticide use can result in pest resurgence such as *Galerucella birmanica* (Singhara beetle) and cereal aphids (Krauss *et al*., 2011; Parameswari *et al*., 2020), as well as a decline in the population of beneficial insects such as natural enemies (Janssen and van Rijn, 2021) (*e.g.*, *Chrysoperla rufilabris* and *Coccinella septempunctata*), and pollinators such as bumblebees (Siviter *et al*., 2018). A successful management of insect pests at local and global scales is a prerequisite for a sustainable oil palm agriculture system. In Southeast Asia, notably in Malaysia, palm oil is a significant export commodity and a major economic driver. The export revenues amounting to approximately RM108.52 billion was reported by Parveez *et al*. (2022). The entire area of land used

[1] Malaysian Palm Oil Board,
6 Persiaran Institusi, Bandar Baru Bangi,
43000 Kajang, Selangor, Malaysia.

* *Corresponding author e-mail: nurulhidayah@mpob.gov.my*

for oil palm cultivation, including those owned by the smallholders, has reached 5.74 million hectares (Parveez *et al*., 2022). Oil palm-cultivated lands are known to be particularly blessed with several ecosystem services (Aulia *et al*., 2020; Norman *et al*., 2019). Insects provide a variety of ecosystem services, including pollination and natural enemies for pest control, that are particularly important for both natural habitations and agriculture (Sáenz-Romo *et al*., 2019).

As an ecosystem function benefits people economically, insect natural enemies play a crucial role in pest control (Koh and Holland, 2015). Implementing beneficial plants in the oil palm landscape can increase the populations of natural enemies as a way to aid biological control conservation (Norman and Othman, 2016). It has been demonstrated that natural enemies such as parasitic and predatory insects are beneficial in suppressing pest species (Basri *et al.*, 1995; Siti Nurulhidayah and Norman, 2016; Siti Nurulhidayah *et al*., 2020). These species coexist in natural ecosystems and may interact with one another in ways that affect the effectiveness of pest regulation (Dainese *et al*., 2017). Norman *et al.* (2017) have identified hymenopterans as a prominent insect order that was known to be the natural enemies of bagworms and other oil palm leaf-eating caterpillars. Parasitoids, specifically hymenopterans, although small in size, are important ecologically and economically (LaSalle and Gould, 1993). Due to their special adaptations toward host concealment, parasitoids perform a unique function in pest population reduction. For example, Cerambycid wood borers were suppressed by generalist parasitoids in the forest industry (Wang *et al*., 2021). Habitat manipulation, in conjunction with conservation biological control implementation in agriculture settings, is known to be instrumental in fostering the populations of natural enemies, while suppressing the pest population (Fiedler *et al*., 2008; Gurr *et al*., 2017).

Bagworm (Lepidoptera: Psychidae) infestations have significantly impacted the oil palm yield, particularly for smallholders (Nur Robaatul Adhawiyah *et al*., 2021; Nurul Afiah *et al*., 2022). Severe infestation can result in yield reductions of up to 43% (Basri, 1993; MPOB, 2016). Bagworms were recorded in over 12% of the estate areas (7811 ha) by 2000, according to a later survey by Ho *et al*. (2011). Malaysia has experienced outbreaks for over five decades (Cheong and Tey, 2012). Currently, outbreaks are still reported, particularly in Perak and Johor (Noorhazwani *et al*., 2017; Nur Robaatul Adhawiyah *et al*., 2021). Despite the existence of efficient control techniques, this problem persists. The current integrated pest management (IPM) strategy for bagworms in Malaysia comprises the aerial application of bio-insecticides and the use of natural pheromone traps (Norman *et al*., 2019). Another technique to increase the populations of predators and parasitoids is habitat manipulation. This includes offering shelter habitat, substitute hosts or prey, or food plants from which nectar and pollen can be acquired (Baggen *et al*., 1999; Shakeel *et al*., 2022). Shelter habitats within the field may consist of plants selected to be beneficial for the natural enemies (Nilsson *et al*., 2016). These plants attract parasitoids and predators by offering a source of nectar to prolong their lifespan and lay eggs (Norman and Othman, 2016).

In the oil palm ecosystem, four species of nectar-producing plants, including *Cassia cobanensis, Euphorbia heterophylla, Antigonon leptopus* and *Turnera subulata*, were observed to be beneficial to the natural enemies of bagworms (Basri *et al*., 2001; Ho *et al*., 2003; Jamian *et al*., 2020). Basri *et al.* (2001) evaluated several beneficial plants in the field for their attraction to main bagworm parasitoids. Parasitism was more prevalent near the flowers. This study investigated three plants: *C. cobanensis*, *E. heterophylla* and *Crotalaria usaramoensis*. Ho *et al*. (2003) explored the topic in greater depth. They tested *C. cobanensis* and *E. heterohylla*, as well as *A. leptopus, C. zanzibarensis, T. subulata* and *Asystasia gangetica*, and a control of mixed grasses. It was observed that the parasitism was more abundant near *C. cobanensis* and *E. heterophylla*. Around the year 2000, it became regular practice to plant *C. cobanensis, E. heterophylla, A. leptopus*, and/ or *T. subulata* in open spaces in Malaysian oil palm plantations (Siti Ramlah *et al*., 2005). Yusdayati *et al.* (2014) later concluded that *Turnera* spp. were more recommended since flowering is continuous compared to other species. *Turnera subulata* (Turneraceae) is a perennial herb which is up to 0.8 m tall with a woody stem base and growing from a thick taproot, with darker bases, thick herb and dark green foliage (Saravanan *et al*., 2018). Its dark-eyed flowers have five obovate cream-colored petals with a yellow base or are pure yellow. Flowers cannot self-pollinate and must rely on another flower to generate seeds. However, the impact of *T. subulata* on the populations of natural enemies and pests has received little attention. As such, this study aimed to address the influence of the flowering beneficial plants on the abundance of the natural enemies and subsequently, their relation to the occurrence of bagworms in the oil palm plantation.

MATERIALS AND METHODS

Study Site

The research location was an oil palm plantation in Bagan Datuk, Perak, Malaysia 3º48′22.13″N, 101º06′8.68″E; (*Figure 1*) that was reported to have a mild infestation with the bagworm, *Pteroma pendula*. The 10 ha site on shallow peat soil comprised twelve-year-old DxP plantings, with generally uniform palm growth. The selection of the sampling location was based on the existence of beneficial plants and with infestation levels exceeding the recommended economic threshold (*i.e.*, more than 10 live larvae per oil palm frond), being given priority (MPOB, 2016; Noorhazwani *et al.*, 2017; Wood and Norman, 2019). *Turnera subulata* was selected as the subject plant, as the groves are easy to establish in the oil palm plantation setting as stated by Yusdayati *et al*. (2014). A total of six oil palm planting blocks were selected with each block approximately one hectare and with *T. subulata* planted around it as an adjacent plant along the road. The distance between each block was 500 m. Three sampling plots were designated inside each block, ranging from the block's edge to its interior. Ten recording palms made up each sampling plot as described by Norman and Basri (2010) in their study of *C. cobanensis* plant. The sampling was conducted for 24 months, from June 2014 to June 2016.

The characteristic of the inter-row area is non-harvesting paths within oil palm rows with approximately nine metres distance between facing palms and covered ten facing palms with approximately 45 m distance, for each sampling plot. While for the *T. subulata* groves area, the size of its planting plot was 2.0 × 0.5 m with a 1.0 m distance between planting plots and planted along the main road and drain. *Turnera subulata* was already planted and maintained by the estate management as one of their management requirements. According to them, 10 g phosphate fertiliser was used during the planting for each plant cutting and empty fruit bunches (EFB) were used to mulch the soil for soil moisture conservation. Propagation was performed through the use of seeds and stem cuttings. Sufficient sunlight is an important factor in maintaining flower production (*Personal communication*).

Evaluation of the Bagworm Population

A monthly census was conducted to assess the field population of *P. pendula*. *Pteroma pendula* were sorted, counted, and recorded according to their life stage. Ten palms were randomly chosen per hectare as census palms. Fronds with a 45° inclination or the upper fronds showing signs of bagworm attack were cut down. Each census palm had at least one frond assessed.

Insect Sampling Techniques and Preservation

In this study, two beneficial insect guilds which consisted of predators and parasitoids, were sampled at *T. subulata* groves and in the oil palm inter-rows. Two sampling techniques were utilised in each plot as follows: i) a sweep net made of muslin cloth with a diameter of 30 cm at the opening and a length of 60 cm, and ii) a yellow sticky trap. Sweep net samplings were carried out inside each planting block by sweeping four times over the grove and along the path, from 9:00 am to 12:00 pm. The yellow sticky trap was mostly used

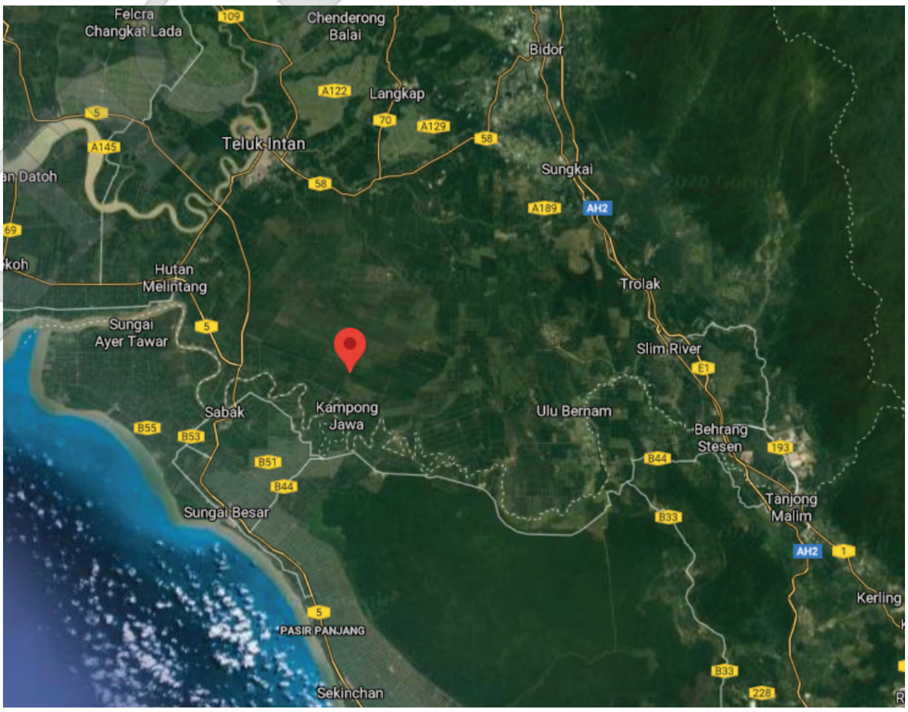

Figure 1. Map of study site in Bagan Datuk, Perak.

to catch flying insects. This square trap measured 48 × 48 cm. It was made of plywood, painted yellow, wrapped in a clear plastic sleeve and sprayed with polybutene gum (Neopeace brand; containing polybutene 16% w/w). The trap was positioned about 1.5 m from the ground. The traps were then placed randomly at the *T. subulata* grove in the study plot and left there for two days. For two consecutive days, the data was collected at 9:00 am on the following morning, each day. The sticky traps were replicated three times inside each plot, in the inter-rows between the oil palm trees (at the non-harvesting path) and *T. subulata* groves. Both sampling techniques were replicated three times each, following the procedure recommended by Norman and Basri (2010). Samplings were carried out monthly. The sampling was conducted in the bright middle of the morning when most insects began to become active. The insects captured by using sweep nets were put into jars containing cotton that had been soaked in ethyl acetate. Meanwhile, the insects captured by sticky traps were carefully collected and transferred into bottles. Since most of the specimens adhered to the sticky trap, some of them were photographed using a digital camera for counting and identification purposes.

In order to assess parasitoid emergence, live bagworm samples (larvae and pupae) were also collected from each block monthly and brought to the laboratory. Thirty recording palms were randomly chosen from each sampling block. Dead specimens were put into plastic vials individually until the emergence of parasitoids, while the live bagworms were reared on oil palm leaflets in transparent cylindrical cages (12.5 cm in diameter x 23.5 cm in height) with ventilated lids until the emergence of parasitoids at a temperature of 24 ± 1°C and 60-70% relative humidity. Daily observations and records of the emergence were made. The collected parasitoids were stored and preserved in 70% alcohol for further identification. Identification of samples up to the family or species level was conducted using a stereo-zoom microscope by referring to "The Handbook of Common Parasitoids and Predators Associated with Bagworms and Nettle Caterpillars in Oil Palm Plantations" by Norman *et al.* (2017).

Statistical Analysis

The two-way ANOVA analysis was carried out to determine whether there were significant differences in the number of natural enemies captured by different sampling techniques in relation to sampling locations. All pairwise multiple comparison procedures (Holm-Sidak method) of significance testing at 5% levels were used for mean comparisons. The correlation coefficient (r) analysis was also carried out to determine the relationship between bagworm occurrence and natural enemies abundance by using SigmaPlot 12.5 software. The figures showing the bagworm population, emergence and monthly captures of insect natural enemies were generated using Microsoft Excel.

RESULTS AND DISCUSSION

It had been observed that the population of the bagworm, *P. pendula*, fluctuated in relation to the abundance of its natural enemies throughout the study duration. *Figure 2* shows the *P. pendula* population fluctuated from undetectable levels to as high as 106.8 ± 13.723 live bagworms per frond (BPF), which exceeded the economic threshold level (ETL). The ETL for *P. pendula* is ten live larvae per oil palm frond (MPOB, 2016; Noorhazwani *et al*., 2017; Wood and Norman, 2019). Two main peaks of the infestation were recorded in November 2014 (90.2 ± 21.653 BPF) and in November 2015 (106.8 ± 13.723 BPF), before fluctuating to a low density and remaining below ETL of less than 10 BPF in the following months.

In September and October 2014, the live larval population of *P. pendula* increased, reaching a peak of 90.2 BPF in November 2014. The sudden increase in the pest population coincided with a lack of parasitoids emerging between September and October 2014 (*Figure 2*). Similar circumstances had been observed before the second peak (highest peak) in November 2015, while no emergence of parasitoids was recorded from August to October 2015. Basri *et al*. (1995) suggested that due to their short life span, the abundance of the parasitoids in the field can fluctuate heavily. After a peak period of abundance, their population can reduce greatly within a short period. Thus, when their abundance is not in sync with the bagworms' life cycle, a subsequent generation of bagworms may evade full natural control, leading to a sudden surge in the infestation.

Although the bagworm population was observed to be fluctuating in this study, a vastly decreasing trend was recorded from the peak bagworm population of 106.8 BPF in November 2015 to less than the ETL (<10 BPF), at 4.31 BPF in December 2015. Thereafter, the population continued to fluctuate at low levels until it reached a non-detectable level during July 2016 and later samplings. According to Cheong *et al*. (2010), the parasitoid community has also been highlighted as one of the mortality mechanisms that has contributed to a nearly 36.7% decrease in the population of bagworms. This suggests that the natural mortality factors by insect natural enemies with the presence of the beneficial plant were sufficient to achieve control.

The activities of natural enemies were monitored based on captures of sticky traps and sweep net (Böckmann and Meyhöfer, 2017; Norman and Basri, 2010; Pobozniak *et al.*, 2020; Shweta and Rajmohana, 2016). Using both techniques, various species of the insect's natural enemies were captured during sampling. The outcomes of the current study revealed that a total of 1035 individuals belonging to at least 20 insect species of two trophic guilds were present in *T. subulata* groves, while at oil palm inter-rows a total of 182 individuals belonging to at least 10 insect species of two trophic guilds were present. A total of 20 parasitoid species (including three unknown species) belonging to seven families namely Ichneumonoidae, Braconidae, Chalcididae, Eurytomidae, Eulophidae, Elasmidae, and Tachinidae (*Table 1*) were captured. As for the predators, three species were recorded belonging to two families, Reduviidae and Cleridae. The reduviid predator species found were *Sycanus dichotomus* and *Cosmolestes picticeps* while the clerid predator found was *Callimerus arcufer* (*Table 1*).

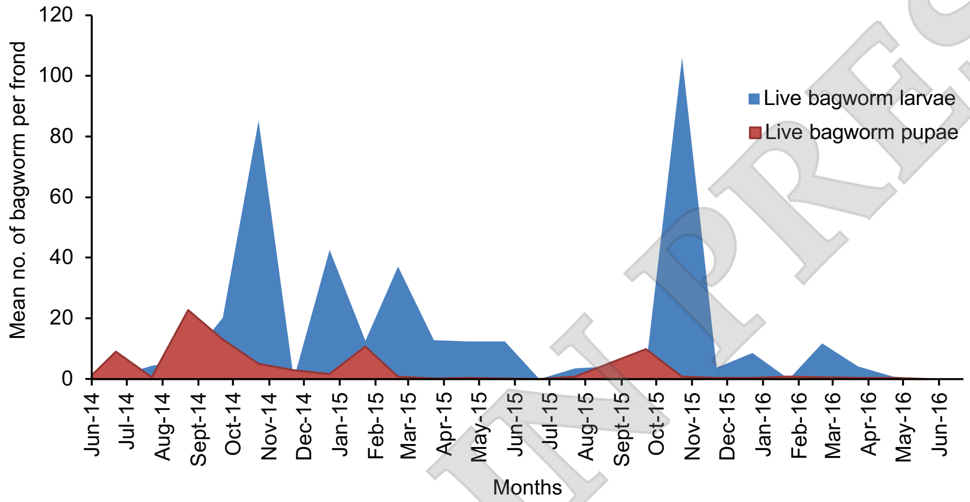

Figure 2. The bagworm, Pteroma pendula *population density at the study area in Bagan Datuk, Perak.*

TABLE 1. THE LIST OF NATURAL ENEMIES SPECIES AND THEIR ABUNDANCE IN *Turnera subulata* GROVES AND OIL PALM INTER ROWS CAPTURED USING STICKY TRAP AND SWEEP NET

Trophic guild	Order	Family	Species	No. of individuals		
				Turnera subulata groves	Oil palm inter rows	Total
Parasitoid	Hymenoptera	Ichneumonoidae	*Spinaria spinator*	26	8	34
			Paraphylax varius	6	6	12
			Buysmania oxymora	4	0	4
			Unidentified	8	0	8
		Eulophidae	*Pediobius anomalus*	2	0	2
			Tetrastichus sp.	4	0	4
			Sympiesis sp.	24	2	26
			Pediobius imbreus	2	0	2
		Braconidae	*Dolichogenidae metesae*	22	6	28
			Apanteles aluella	2	0	2
			Aulosaphes psychidivorus	2	0	2
		Chalcididae	*Brachymeria lugubris*	150	14	164
			Brachymeria carinata	384	32	416
		Elasmidae	*Elasmus* sp.	6	0	6
			Unidentified	2	0	2
		Eurytomidae	*Eurytoma* sp.	4	0	4
	Diptera	Tachinidae	Unidentified	4	2	6
Predator	Hemiptera	Reduviidae	*Cosmolestes picticeps*	199	102	301
			Sycanus dichotomus	2	2	4
	Coleoptera	Cleridae	*Callimerus arcufer*	2	8	10
		Total individuals		853	182	1 035

The abundance of natural enemies in *T. subulata* groves revealed that *B. carinata* represented the largest percentage with 45% (384 individuals). *Cosmolestes picticeps* and *Brachymeria lugubris* represented 24% (199 individuals) and 18% (150 individuals), respectively. Other parasitoids and predators were recorded at low levels (<4%) within each species. Based on the findings in this study, it is revealed that *B. carinata* represented the highest number of individuals captured and present in all sampling plots (*Figure 3*).

Meanwhile, at oil palm inter-row plots, a total of 182 individuals comprising 70 parasitoids and 112 predators, were captured using sticky traps and sweep nets. There were seven different parasitoid species in all, and they were divided into five different families: Ichneumonoidae, Braconidae, Chalcididae, Eulophidae, and Tachinidae. Whereas, three species of predators, from two families (Reduviidae and Cleridae) were recorded. Contrasting to *T. subulata* groves, *C. picticeps* was discovered to be the most prominent species, representing 58% of all captures (102 individuals), followed by *B. carinata* (18%: 32 individuals), *B. lugubris* (7%: 14 individuals). Other species were recorded at lower levels (<5%) (*Figure 3*). The occurrence of more predators than parasitoids in inter-row plots was in contrast with the finding in *T. subulata* plots. In the inter-row plots, where there were no beneficial plants, the predators appear to predominate over the parasitoids. The predators have frequently been discovered residing around the ground covers, which was also suggested by Norman and Basri (2010). While the parasitoid prefers to dwell on *T. subulata* due to the shelter and nectar source. The lack of parasitoids in the oil palm inter-row could occur in an area with palms that are physically uniform in height and size. According to Mohd Hanysyam *et al*. (2013), this situation might not be ideal for the parasitoids' activities due to insufficient intense sunlight or availability of food. However, it might provide sustenance for naturally occurring interactions with bagworms, which act as hosts for their reproduction.

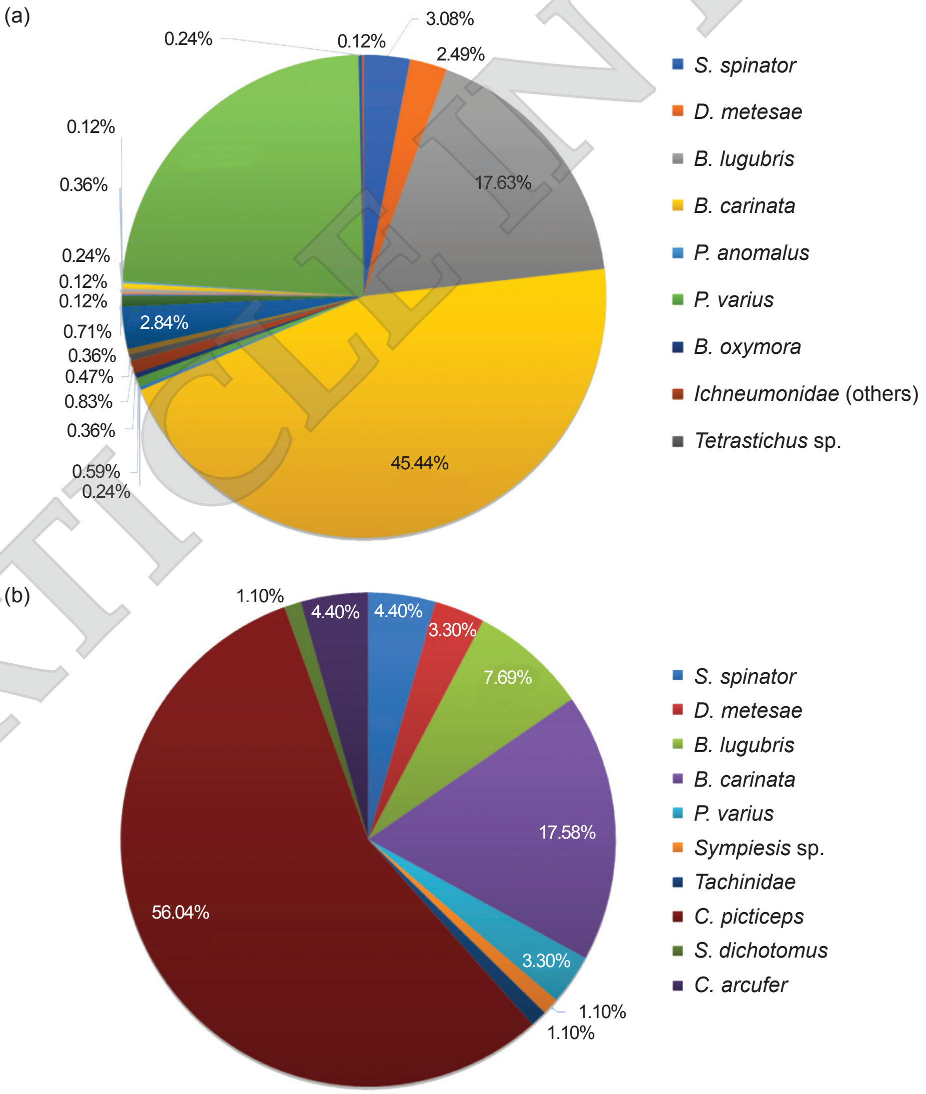

Figure 3. The percentage of natural enemies species captured at (a) Turnera subulata *groves and (b) oil palm inter-rows.*

A greater presence of both parasitoids and predators was recorded in *T. subulata* groves compared to the oil palm inter-rows (*Figure 4* and *5*). The increase in the observation of the natural enemies in the groves of *T. subulata* coincided with the negligible presence of bagworms on the oil palm fronds. The insect natural enemies are drawn to the groves by the abundance of incentives (*i.e.,* nectar and shelter). As pointed out by Jonsson *et al.* (2010), habitat manipulation, in this case, by offering shelters and resources limited in the agroecosystems, has proven to be effective in conserving the natural enemies.

Besides the reduviid predator *C. picticeps*, the prominent parasitoids found at all sampling sites were mostly chalcids (*B. lugubris* and *B. carinata*) and braconids (*Dolichogenidea metesae*). The results showed that the sweep net consistently captured a wider range of natural enemies than the sticky trap, as shown in *Figures 5* and *6*. According to Shweta and Rajmohana (2016), this could be due to the majority of the natural enemies being the resident population. Sweep nets are regarded as one of the most simple and effective ways to catch hymenopteran parasitoids as well as other types of insects (Daniel *et al*., 2018). Results showed that the overall effect of the sampling technique on natural enemies' capture was highly significant (F = 15.969; df = 1; P <0.001). Similarly, the sampling location also exhibited a highly significant effect on the natural enemy captures (F = 13.252; df = 1; P <0.001). Overall, the interaction between the sampling technique and sampling locations was significant (F = 9.125; df = 1; P = 0.003) (*Table 2*). These findings demonstrate that the natural enemies' activities shifted to the *T. subulata* plant groves due to the

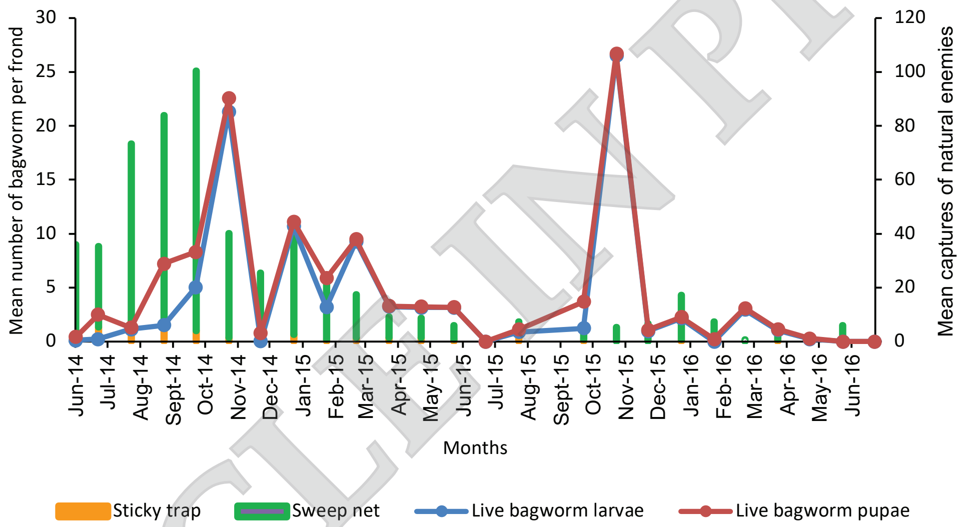

Figure 4. Mean of monthly captures of insect natural enemies using sticky trap and sweep net on Turnera subulata *groves in relation to bagworm population.*

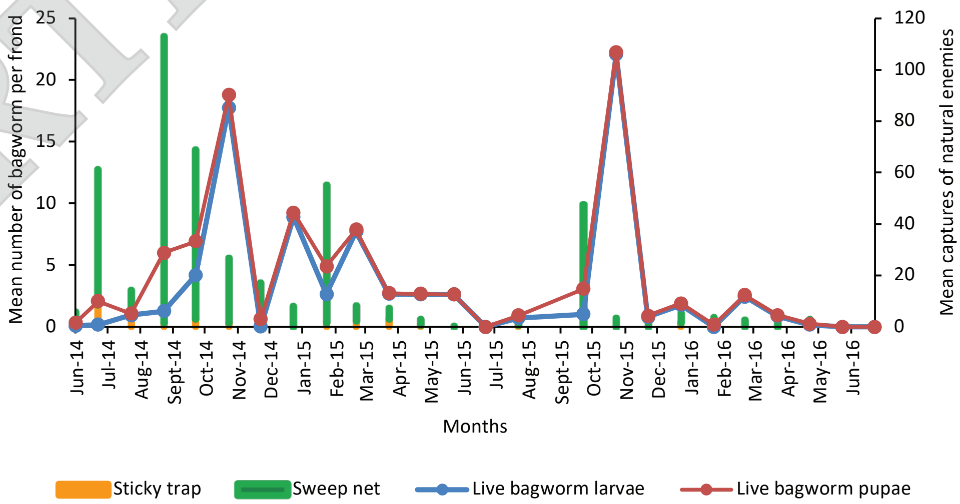

Figure 5. Mean of monthly captures of insect natural enemies using sticky trap and sweep net in oil palm inter-row in relation to bagworm population.

low and fluctuated number of bagworm hosts in the oil palm inter-rows. This also implies that the parasitoids tended to congregate around their food sources (in *T. subulata*). This situation can be seen in the sampling where *T. subulata* grove plots had recorded a constantly higher number of captures compared to oil palm inter-rows (*Table 1*).

The observation of natural enemies' emergence was also conducted in the laboratory. Overall, 222 natural enemies from six species of Hymenopteran parasitoids and one species of Coleopteran predator were associated and found to have emerged from *P. pendula* that had been sampled throughout the sampling period in all experimental blocks (*Figure 6*). The most prominent family was Eulophidae, which included three species (*Pediobius imbrues*, *Pediobius anomalus* and *Pediobius elasmi*) and 191 individuals, which constituted 86% of the total individuals found emerging from the bagworms, followed by Ichneumonidae (7.2%), Cleridae (5.9%) and Chalcididae (0.9%). The most abundant parasitoid species was *P. imbrues* (74.8%), followed by *P. anomalus* (10.8%), *P. varius* (5.0%), an unidentified Ichneumonid (2.3%), *B. carinata* (2.9%), and *P. elasmi* (0.5%). A species of Clerid predator, *C. arcufer* (representing 5.9%) was also found to emerge from the bagworm. The percentage of natural enemies' species is displayed in *Figure 6*.

While the correlation analysis between natural enemies (from emergence, sweep net and sticky trap data) and larval stages of *P. pendula* gave a low coefficient (r) value, a significant positive correlation was observed between natural enemies (captured by sweep net and sticky trap) and pupal stage of *P. pendula* ($r = 0.659$; $r^2 = 0.434$; $P < 0.001$) (*Table 3*). This indicates a higher occurrence of the emergence of parasitoids from the pupal stage of *P. pendula* compared to larval stages, this finding was supported by earlier finding by Basri *et al*. (1995). This is explained by the fact that different parasitoid species have different life spans, some of which may not be synced with the duration of

TABLE 2. TWO-WAY ANOVA ANALYSIS ON THE NUMBER OF NATURAL ENEMIES CAPTURED BY DIFFERENT SAMPLING TECHNIQUES IN RELATION TO SAMPLING LOCATIONS

Source of variation	Degree of freedom	Sum of squares	Mean square	F-value	*P*-value
Sampling technique	1	173.925	173.925	15.969	**<0.001**
Sampling location	1	144.325	144.325	13.252	**<0.001**
Sampling technique x Sampling location	1	99.381	99.381	9.125	**0.003**
Residual	92	1 001.987	10.891		
Total	95	1 419.618	14.943		

Note: Numbers in bold font indicate a significant difference ($P < 0.05$).

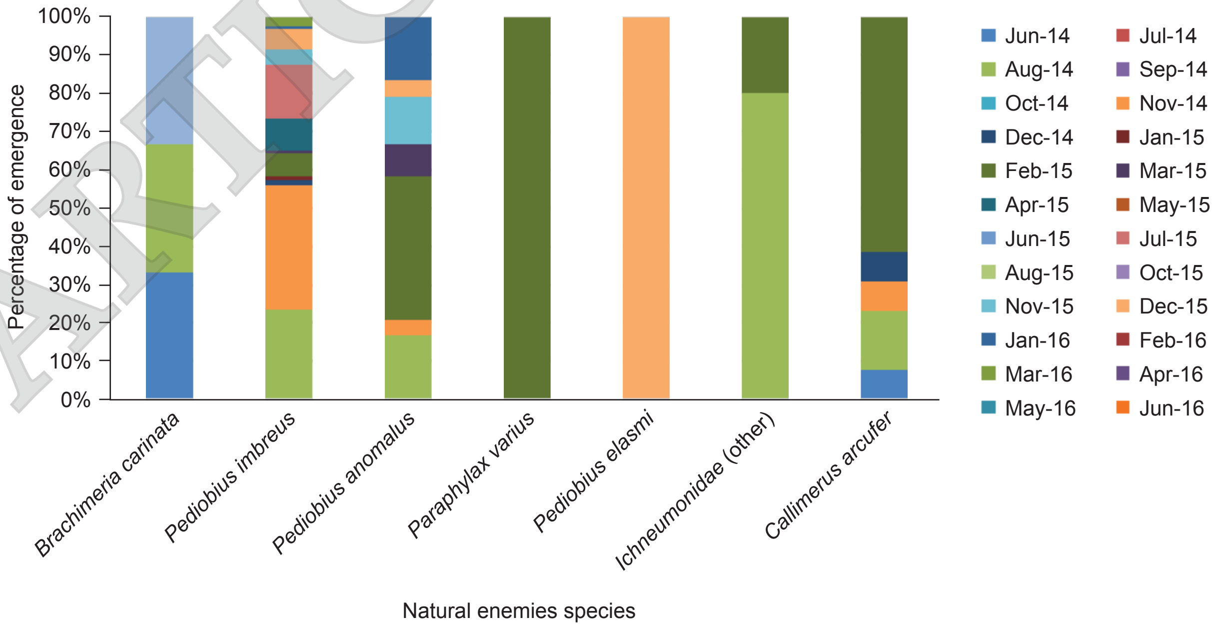

Figure 6. The percentage of species accumulation emergence for natural enemies throughout the study duration.

their preferred host stages. This did not represent the entire degree of parasitism because the parasitoids' life span was only a fraction of that of the bagworm, and sampling was done in a short time per sampling activity. Factors such as direct disturbances, pesticide spraying, unpredictable humidity and temperature can also influence parasitism activity, resulting in a decrease in fauna diversity in oil palm plantations (Mohd Hanysyam *et al*., 2013).

The overall diversity and species richness of natural enemies recorded were calculated with several diversity indices and presented in *Table 4*. The S', D', H' and E' values varied between the sampling locations. The highest natural enemies' diversity was found in the *T. subulata* groves, which has a Shannon-Wiener index diversity of 1.747 as compared to oil palm inter-rows (1.447). The index trend is similar to Simpson's index, which is higher on *T. subulata* groves (0.406). These values are supported by the dominant and higher abundance of natural enemies on *T. subulata* groves (*Table 1*) that indicated that 82% of total individuals captured using both sampling techniques was dominated by Chalchidae family (580 individuals). Evennes index provides information on composition and richness, with oil palm inter-rows having the greatest value (0.628) as compared to *T. subulata* groves (0.583). In terms of species richness, *T. subulata* groves were twice as rich as oil palm inter-rows. The greater value of H' in the *T. subulata* area is influenced by the values of E' (E =0.583) and D' (D = 0.406). In the case of oil palm inter-rows, the decreased value of H (H = 1.447) is attributable to less insect diversity since the area was shaded by the oil palm canopy. This finding demonstrated that the practices of establishing the beneficial plants in the oil palm plantation were able to exploit the natural enemies (parasitoids and predators) in regulating the bagworm population, as supported by Mohd Hanysyam *et al.* (2013).

Different parasitoid species were discovered in this study. Some behaved as primary parasitoids, hyperparasitoids, and some species might fit into both categories, such as *P. anomalus*, *P. imbrues*, *Elasmus* sp. and *Tetrastichus* sp. These similar species have also been found on other species of bagworms, such as *Metisa plana* and *Mahasena corbetti* (Basri *et al.,* 1995). According to Basri *et al*. (1995), the primary parasitoids were the dominant cause of host mortality from the third to the final instar, proving that they were the predominant main cause of bagworm decline. These are the ecosystem service providers whose agents are crucial in keeping bagworm populations below threshold levels.

Apart from the commonly found *C. picticeps*, other predatory species with the capacity to prey on the bagworms include *S. dichotomus* (Hemiptera: Reduviidae) and *C. arcufer* (Coleoptera: Cleridae) (Siti Nurulhidayah *et al*., 2020). This shows that while the presence of the bagworms' natural enemies is often scarce, they have the potential to multiply and impose natural control. Nevertheless, the presence of alternative hosts may also aid in maintaining the population, particularly for the primary parasitoids (Basri *et al*., 1995). As stated by Basri *et al*. (1995), in addition to the natural control provided by predators and parasitoids, bagworm mortality can also be caused by infertility, empty bags, desiccation and disintegration, fungal infection, host feeding, and incomplete pupation.

TABLE 3. THE CORRELATION COEFFICIENT BETWEEN BAGWORM AND NATURAL ENEMIES

	Natural enemies (captured by sticky trap and sweep net)			Natural enemies (emergence)		
	r	r^2	*P*-value	R	r^2	*P*-value
Bagworm (all stages)	0.176	0.0310	0.411	0.237	0.0564	0.264
Bagworm (larval stage)	0.0399	0.00159	0.853	0.245	0.0599	0.249
Bagworm (pupal stage)	0.659	0.434	<0.001*	0.0189	0.000358	0.930

Note: r = correlation coefficient value; r^2 = linear regression value; * = significant value at $P < 0.01$.

TABLE 4. COMPARISON OF NATURAL ENEMIES AT THE SAMPLING LOCATIONS USING DIFFERENT DIVERSITY INDICES

Sampling location	Number of individuals	Species Richness (S')	Simpson's Index (D')	Shannon-Wiener Index (H')	Evenness (E')
Turnera subulata groves	853	20	0.406	1.747	0.583
Oil palm inter-rows	182	10	0.247	1.447	0.628
Total	1 035	30	0.653	3.194	1.211

Natural enemies such parasitoids and predator groups have a significant role in population regulation and fluctuation of the bagworm population in oil palm (Halim *et al*., 2017; Siti Nurulhidayah *et al*., 2020). In order to maintain the population of natural enemies for the long-term control of bagworms, Norman and Mohd Basri (2010) strongly recommends the need of planting beneficial plants inside the vicinity of oil palm plantations. The presence of beneficial plants that were planted along the roadside within the plantation enhanced the availability and abundance of the natural enemies in the plantations.

Other beneficial flowering plants, including *C. cobanensis, A. leptosus* and *T. ulmifolia*, have been proven to be effective in natural insect pest management in oil palm environments, particularly in Malaysia (Basri *et al*., 1999). The constant establishment of these beneficial plants in the plantations can greatly reduce the presence of the bagworm or other insect pest population in the long run as a crucial part of integrated pest management (IPM) and as an ecosystem service, as stated by Norman *et al*. (2019). The natural flowering weed species found in the experimental plots were represented by shrubs, such as *Asystasia intrusa* and *Nephrolepis* fern species. The findings indicate that planting suitable flowering species of beneficial plants as adjacent planting in patches may be useful in promoting the presence of beneficial insects in oil palm surroundings and could be part of a sustainable oil palm ecosystem. Thus, it is strongly recommended that the planting of beneficial plants within the surroundings of the oil palm landscape in order to sustain the population of natural enemies for long-term control of bagworms. The rationale behind planting nectar-producing, beneficial plants is to increase the lifespan of insect natural enemies and retain them in the field to suppress the population of the leaf-eating pest. These studies demonstrated that low populations of bagworms are maintained below their threshold levels with the presence of natural enemies, which contribute to an ecological balance.

Additionally, the size and life stage of the host may also have an impact on the natural enemies' acceptance of the host, particularly parasitoids. A study by Harvey *et al*. (2013) demonstrated that it is possible that competition between parasitoids of the same species or different species will attack a similar host, and that they will be competing for dominance of host resources, which will result in host suppression. It is proven that parasitoids and predators communities with the presence of beneficial plants enrolled as successful biological control agents for bagworms in oil palm plantations.

CONCLUSION

According to the research findings, it can be concluded that the interaction between the sampling technique and sampling locations was significant ($p<0.05$). The highest natural enemies diversity index and species richness were found in the *T. subulata* groves. This study represents that the higher natural enemies' abundance obtained by the establishment of *T. subulata* in the landscape surrounding the oil palm plantation enhanced the conservation biological control of the *P. pendula*. The finding suggests that *T. subulata* as ground cover in patches could be established to encourage the propagation of natural enemies and could be part of a sustainable oil palm management system. This information will help us understand whether there are adequate natural enemies to maintain an equilibrium in the bagworm population. The environmental alteration would be appropriate for bagworm control since improving the environment is better to ensure that the natural enemies continue to survive and thrive therein.

ACKNOWLEDGEMENT

We would like to thank the Director-General, Director of Biology and Sustainability Division, and extend our appreciation for the assistance given by the entire team of the Entomology and Ecology Laboratory (Noor Hasan Mohd Yob, Hajijah Shamsuddin, Tunku Akhirudin T. Aris, Zuriahti Khamis and Dr. Norman Kamarudin).

REFERENCES

Aulia, A F; Sandhu, H and Millington, A C (2020). Quantifying the economic value of ecosystem services in oil palm dominated landscapes in Riau province in Sumatra, Indonesia. *Land, 9(6)*: 194. DOI: 10.3390/land9060194.

Baggen, L R; Gurr, G M and Meats, A (1999). Flowers in tri-trophic systems: Mechanisms allowing selective exploitation by insect natural enemies for conservation biological control. *Entomol. Exp. Appl., 91(1)*: 155-161. DOI: 10.1046/j.1570-7458.1999.00478.x.

Basri, M W (1993). Life history, ecology and economic impact of the bagworm, *Metisa plana* Walker (Lepidoptera: Psychidae), on the oil palm, *Elaeis guineensis* Jacquin (Palmae), in Malaysia. Ph.D thesis, University of Guelph. 231 pp.

Basri, M W; Norman, K and Hamdan, A B (1995). Natural enemies of the bagworm *Metisa plana*

(Lepidoptera: Psychidae) and their impact on host population regulation. *Crop Prot., 14(8)*: 637-645. DOI: 10.1016/0261-2194(95)00053-4.

Basri, M W; Simon, S; Ravigadevi, S and Othman, A (1999). Beneficial plants for the natural enemies of the bagworm in oil palm plantations. *Proc. of the 1999 PORIM International Palm Oil Congress – Emerging Technologies and Opportunities in the Next Millennium.* PORIM, Bangi. p. 441-455.

Basri, M W; Norman, K and Othman, A (2001). Field impact of beneficial plants on the parasitism levels of the bagworm, *Metisa plana* (Lepidoptera: Psychidae). *Proc. of the PIPOC 2001 International Palm Oil Congress - Cutting-edge Technologies for Sustained Competitiveness*: *Module 1 - Agriculture, Biotechnology and Sustainability Conference (unedited)*. MPOB, Bangi. p. 441-445.

Böckmann, E and Meyhöfer, R (2017). Sticky trap monitoring of a pest–predator system in glasshouse tomato crops: are available trap colours sufficient? *J. Appl. Entomol., 141(5)*: 339-351. DOI: 10.1111/jen.12338.

Cheong, Y L; Sajap, A P; Hafidzi, M N; Omar, D and Abood, F (2010). Outbreaks of bagworms and their natural enemies in an oil palm, *Elaeis guineensis*, plantation at Hutan Melintang, Perak, Malaysia. *J. Entomol., 7(3)*: 141-151. DOI: 10.3923/je.2010.141.151.

Cheong, Y L and Tey, C C (2012). Understanding pest biology and behaviour for effective control of oil palm bagworms. *The Planter, 88(1039)*: 699-715.

Dainese, M; Schneider, G; Krauss, J and Steffan-Dewenter, I (2017). Complementarity among natural enemies enhances pest suppression. *Sci. Rep., 7*: 8172. DOI: 10.1038/s41598-017-08316-z.

Daniel, J A; Ramaraju, K; Kumar, S M; Jeyaprakash, P and Chitra, N (2018). A study on five sampling methods of parasitic hymenopterans in the rice ecosystem. *J. Biol. Control, 32(3)*: 187-192. DOI: 10.18311/jbc/2018/22104.

Fiedler, A K; Landis, D A and Wratten SD (2008). Maximizing ecosystem services from conservation biological control: The role of habitat management. *Biol. Control, 45*: 254-271. DOI: 10.1016/j.biocontrol.2007.12.009.

Gurr, G M; Wratten, S D; Landis, D A and You, M (2017). Habitat management to suppress pest populations: Progress and Prospects. *Annu. Rev. Entomol., 62*: 91-109. DOI: 10.1146/annurev-ento-031616-035050.

Halim, M; Muhaimin, A M D; Syarifah Zulaikha, S A; Nor Atikah, A R; Masri, M M M and Yaakop, S (2017). Evaluation of infestation in parasitoids on *Metisa plana* Walker (Lepidoptera: Psychidae) in three oil palm plantations in Peninsular Malaysia. *Serangga, 22(2)*: 135-149.

Harvey, A J; Poelman, E H and Tanaka, T (2013). Intrinsic inter- and intraspecific competition in parasitoid wasps. *Annu. Rev. Entomol., 58*: 333-351. DOI: 10.1146/annurev-ento-120811-153622.

Ho, C T; Ibrahim, Y and Khoo, K C (2011). Infestations by the bagworms *Metisa plana* and *Pteroma pendula* for the period 1986-2000 in major oil palm estates managed by Golden Hope Plantation Berhad in Peninsular Malaysia. *J. Oil Palm Res., 23*: 1040-1050.

Ho, C T; Khoo, K C; Yusof, I and Dzolkhifli, 0 (2003). Comparative studies on the use of beneficial plants for the natural suppression of bagworm infestation in oil palm plantations. *Proc. of the 1999 PORIM International Palm Oil Congress – Agriculture Conference*. MPOB, Bangi. p. 372-424.

Jamian, S; Adam, N A; Noor, H M; Zulperi, D; Asib, N; Muhamad, R; Mokhtar, A S; Abdul Wahab, M A; Azhar, B; Sidi, M and Maamor, A (2020). The effect of plant volatiles on plant preference by the predatory insect, *Sycanus dichotomus* Stal. (Hemiptera: Reduviidae) in oil palm plantation. *J. Oil Palm Res., 32(3)*: 471-479. DOI: 10.21894/jopr.2020.0053.

Janssen, A and van Rijn, P C J (2021). Pesticides do not significantly reduce arthropod pest densities in the presence of natural enemies. *Ecol. Lett., 24*: 2010-2024. DOI: 10.1111/ele.13819.

Jonsson, M; Wratten, S D; Landis, D A; Tompkins, J M L and Cullen, R (2010). Habitat manipulation to mitigate the impacts of invasive arthropod pests. *Biol. Invasions, 12(9)*: 2933-2945. DOI: 10.1007/s10530-010-9737-4.

Koh, I and Holland, J D (2015). Grassland plantings and landscape natural areas both influence insect natural enemies. *Agric. Ecosyst. Environ., 199*: 190-199. DOI: 10.1016/J.AGEE.2014.09.007.

Krauss, J; Gallenberger, I and Steffan-Dewenter, I (2011). Decreased functional diversity and biological pest control in conventional compared to organic crop fields. *PLoS ONE, 6(5)*: e19502. DOI: 10.1371/journal.pone.0019502.

LaSalle, J and Gould, I D (1993). Hymenoptera: Their biodiversity, and their impact on the diversity of other organisms. CAB International. Wallingford, UK. p. 1-26.

Mohd Hanysyam, M N; Fauziah I; Siti Kahiriyah, M H; Fairuz, K; Mohd Rasdi, Z; Nurul Zfarina; Ismail, R and Norazliza, R (2013). Assessment on the diversity of parasitoids of bagworms (Lepidoptera: Psychidae) in FELDA Gunung Besout 6, Sungkai, Perak. *2013 IEEE Symposium on Humanities, Science and Engineering Research (SHUSER)*. p. 130-135.

MPOB (2016). *Standard Operating Procedures (SOP) Guidelines for Bagworm Control*. 1st edition. MPOB, Bangi. 32 pp.

Nilsson, U; Rännbäck, L M; Anderson, P; Björkman, M; Futter, M and Rämert, B (2016). Effects of conservation strip and crop type on natural enemies of *Delia radicum*. *J. Appl. Entomol.*, *140(4)*: 287-298.

Noorhazwani, K; Siti Ramlah, A A; Mazmira, M M M; Najib, Che Ahmad Hafiz, C M and Norman, K (2017). Controlling *Metisa plana* Walker (Lepidoptera: Psychidae) outbreak using *Bacillus thuringiensis* at an oil palm plantation. *J. Oil Palm Res., 29(1)*: 47-54. DOI: 10.21894/jopr.2017.2901.05.

Norman, K; Basri, M W and Zulkefli, M (2017). *Handbook of Common Parasitoids and Predators Associated with Bagworms and Nettle Caterpillars in Oil Palm Plantations*. MPOB, Bangi. 30 pp.

Norman, K and Basri, M W (2010). Interactions of the bagworm, *Pteroma pendula* (Lepidoptera: Psychidae), and its natural enemies in an oil palm plantation in Perak. *J. Oil Palm Res., 22(1)*: 758-764.

Norman, K and Othman, A (2016). Diversity and activity of insect natural enemies of the bagworm (Lepidoptera: Psychidae) within an oil palm plantation in Perak, Malaysia. *J. Oil Palm Res., 28(3)*: 296-307.

Norman, K; Idris, A S and Mazmira, M M M (2019). Prospects in sustainable control of oil palm pests and diseases through the enhancement of ecosystem services - The way forward. *J. Oil Palm Res., 31(3)*: 381-393.

Nurul Afiah, S M J; Khairunniza-Bejo, S; Rashid, A M; Nur Azuan, H; Mazmira, M M M and Noorhazwani, K (2022). Identification of bagworm (*Metisa plana*) instar stages using hyperspectral imaging and machine learning techniques. *Comput. Electron. Agric., 194:* 106739. DOI: 10.1016/j.compag.2022.106739.

Nur Robaatul Adhawiyah, M A N; Noorhazwani Kamarudin; Mohd Fahmi Keni; Mohd Najib Ahmad and Mohamed Mazmira Mohd Masri (2021). Impact of multiple aerial spraying of *Bacillus thuringiensis* on bagworm control in oil palm smallholdings in Johor, Malaysia. *Serangga, 26(4)*: 113-123.

Parameswari, E; Davamani, V; Ilakiya, T; Arulmani, S and Prithiv Raj, V (2020). Impact of pesticides on environment. *Biotica Research Today, 2(5)*: 136-138.

Parveez, G K A; Kamil, N N; Zawawi, N Z; Ong-Abdullah, M; Rasuddin, R; Loh, S K; Selvaduray, K R; Hoong, S S and Idris, Z (2022). Oil palm economic performance in Malaysia and R&D progress in 2021. *J. Oil Palm Res., 34(2)*: 185-218. DOI: 10.21894/jopr.2022.0036.

Pobozniak, M; Tokarz, K and Musynov, K (2020). Evaluation of sticky trap colour for thrips (Thysanoptera) monitoring in pea crops (*Pisum sativum* L.). *J. Plant Dis. Prot., 127*: 307-321. DOI: 10.1007/s41348-020-00301-5.

Sáenz-Romo, M G; Veas-Bernal, A; Martínez-García, H; Campos-Herrera, R; Ibáñez-Pascual, S; Martínez-Villar, E; Pérez-Morenoa, I and Marco-Mancebón, V S (2019). Ground cover management in a Mediterranean vineyard: Impact on insect abundance and diversity. *Agric. Ecosyst. Environ., 283*: 106571. DOI: 10.1016/j.agee.2019.106571.

Saravanan, M; Senthilkumar, P; Kalimuthu, K; Rajalakshmi, G and Vajjiram, M C (2018). Regeneration of plants from derived callus of *Turnera subulata* SM - An Important Medicinal Herb. *J. Biosci., 5(2)*: 64-70.

Shakeel Q; Ali, S; Raheel, M; Bajwa, R T; Aqueel, M A; Iftikhar, Y; Ajmal, S and Tariq, K (2022). Habitat manipulation in crops for integrated insect pest and disease management. *Adv. In Integrated Pest Management Technology*. Springer, Cham. p. 83-120. DOI: 10.1007/978-3-030-94949-5_5.

Shweta, M and Rajmohana, K (2016). A comparison of efficiencies of sweep net, yellow pan trap and malaise trap in sampling Platygastridae (Hymenoptera: Insecta). *J. Exp. Zool. India, 19(1)*: 393-396.

Siti Nurulhidayah, A and Norman, K (2016). Growth and longevity of the insect predator, *Sycanus dichotomus* Stal. (Hemiptera: Reduviidae) fed on live insect larvae. *J. Oil Palm Res., 28(4)*: 471-478.

Siti Nurulhidayah, A; Mazmira, M M M and Norman, K (2020). Assessment on voracity and predation by predator, *Sycanus dichotomus* Stal. (Hemiptera: Reduviidae) to oil palm bagworm, *Pteroma pendula*. *J. Oil Palm Res., 32(3)*: 480-487. DOI: 10.21894/jopr.2020.0040.

Siti Ramlah, A A; Basri, M W; Mohd Najib, A and Mazmira, M M M (2005). Integrated pest management: Terakil-1, *Cassia cobanensis* and beneficial insects for controlling of bagworms infestation in Malaysia. *Proc. of the PIPOC 2005 International Palm Oil Congress: Technologies Breakthroughs and Commercialization the Way Forward*. MPOB, Bangi. p. 660-690.

Siviter, H; Brown, M J F and Leadbeater, E (2018). Sulfoxaflor exposure reduces bumblebee reproductive success. *Nature, 561(7721)*: 109-112. DOI: 10.1038/s41586-018-0430-6.

Wang, X; Wang, X Y; Kenis, M; Cao, L M; Duan, J J; Gould, J R and Hoelmer, K A (2021). Exploring the potential for novel associations of generalist parasitoids for biological control of invasive woodboring beetles. *Biol. Control, 66:* 97-112. DOI: 10.1007/s10526-020-10039-6

Wood, B J and Norman, K (2019). Bagworm (Lepidoptera: Psychidae) infestation in the centennial of the Malaysian oil palm industry – A review of causes and control. *J. Oil Palm Res., 31(3):* 364-380. DOI: 10.21894/jopr.2019.0032.

Yusdayati, R; Ahmad, A H and Hamid, N H (2014). Diversity and distribution of natural enemies (predators and parasitoids) of bagworms (Lepidoptera: Psycidae) on selected host plants in an oil palm plantation. *The Planters, 90*: 91-101.

Ziolkowska, E; Topping, C J; Bednarska, A J and Laskowski (2021). Supporting non-target arthropods in agroecosystems: Modelling effects of insecticides and landscape structure on carabids in agricultural landscapes. *Sci. Total Envi., 774*: 145746. DOI: 10.1016/j.scitotenv.2021.145746.