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ARTHROPOD FAUNA OF OIL PALM INFLORESCENCE (*Elaeis guineensis*), WITH NOTES ON THEIR ECOLOGICAL ROLES IN A PLANTATION IN TERENGGANU, MALAYSIA

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ABSTRACT

Arthropod communities at oil palm inflorescence, specifically the insects, are known to forage for floral resources and hence act as pollinators to the palm tree. However, their activities at the inflorescence other than as pollinators are rarely explained. This study was conducted at an oil palm plantation located at Hulu Terengganu District, in Terengganu state, Peninsular Malaysia. Arthropod fauna was extracted from 15 male and female inflorescences for identification, and bottle traps were set up to capture the arthropod fauna for pollen load observations. A total of 14 insect taxa, two spiders and a millipede were recorded in this study. A high abundance of Elaeidobius kamerunicus *was recorded and with high conspecific pollen loads on their bodies further confirming their importance as pollinators for the palm tree. Predation activity by an earwig on larvae of the insect pollinators which used the male inflorescence as a breeding site was observed in this study. Other than utilising the oil palm inflorescence as a preying and breeding ground, earwigs, ants, wasps and flies were also likely pollinators for the oil palm tree. Hence this study adds more understanding of the ecological role of arthropods in the oil palm plantations in Malaysia.*

Keywords: conspecific pollen, earwig, larvae, pollinator, predator.

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INTRODUCTION

The African oil palm, *Elaeis guineensis* originated from the African continent and is widely cultivated in Southeast Asia, particularly in Malaysia and Indonesia, the two primary producers of palm oil products in the world (Corley and Tinker, 2016). During its early introduction in Malaysia, this palm was originally believed to be mainly pollinated by wind (Hardon and Turner, 1967; Turner, 1978), before further observations indicated that insect pollinators particularly the oil palm weevil, *Elaeidobious kamerunicus* are crucial in the pollination of this palm (Syed, 1979). Before the introduction of this weevil in Malaysia in 1980 (Basri *et al.*, 1983), assisted pollination was practised to improve the fruit yield of this important cash crop (Teo, 2015). However, assisted pollination also resulted in poor fruit sets due to the difficulty in applying pollen grains to the inner part of the oil palm inflorescence (Harun and Noor, 2002). Insects such as the hymenopteran bees and dipteran flies are the major pollinator groups for agricultural crops (Wojcik, 2021). In the case of commercial oil palm (Genus *Elaeis*), the insect pollinators are predominantly the coleopteran weevils from the Genus *Elaeidobius* (Appiah and Agyei-Dwarko, 2013; Li *et al.*, 2019; Melendez and Ponce, 2016).

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The activities of insects in oil palm inflorescences were always described in relation to their activity to forage for food (Rizali *et al.*, 2019; Sambathkumar and Ranjith, 2011; Syed, 1979). Other than foraging for the flower resources, the insect also visits the oil palm inflorescence to prey on other insects and also for appropriate living space and breeding sites (Li *et al.*, 2019; Muhammad Luqman *et al.*, 2017; Rizali *et al.*, 2019; Yue *et al.*, 2015). Other than the extensive studies on the relationship between *E. kamerunicus* and the oil palm inflorescence which has indicated its crucial role in fruit yield of the economically important palm tree (Yousefi *et al.*, 2020), further investigation on the ecological significance of the arthropod communities at the oil palm inflorescence is rarely explored (Li *et al.*, 2019). Competition between the visitors, or predation on the main pollinators, for example, could influence the fruit yield. Moreover, the pollination success of the *E. kamerunicus* population was found to be highly influenced by climatic conditions (Yousefi *et al.*, 2020).

The oil palm tree produces the male and female inflorescences alternately (Adam *et al.*, 2011; Sambathkumar and Ranjith, 2015), hence requiring pollinating agents to move the pollen grains from the male to the female inflorescence. Thus, any flower visitors could be considered pollinators, even if they are visiting for ovipositing or preying on the inflorescences. In Malaysia, other than *E. kamerunicus*, *Pyroderces* sp. (cosmeth moth) and *Thrips hawaiiensis* (Hawaiian flower thrips) are the only known native insect pollinators for the oil palm although these insects are less efficient (Wahid and Kamarudin, 1997). We believe that other arthropod flower visitors could also act as pollinators for the oil palm, hence this study was conducted to explore the potential significance of other arthropods as pollinators of the palm trees. The information gained from this study could improve our understanding of the ecosystem services provided by the arthropod fauna in the oil palm plantation, particularly in relation to the pollination success of the palm trees in Peninsular Malaysia. Hence, the knowledge of the ecological and economically important arthropod communities is valuable not only to the scientific community but also to industrial players as it enables biodiversity-friendly management in the oil palm plantation.

MATERIALS AND METHODS

Study Site

Samplings of arthropods were carried out at Ladang TDM Jerangau (hereafter Ladang Jerangau), owned by Terengganu Development Management (TDM) Sdn. Bhd., Terengganu state in Peninsular Malaysia (*Figure 1*). The study site is located in Hulu Terengganu District (4°57′45″N 103°9′59″E), situated about 65 km from Kuala Terengganu. The palm trees (*E. guineensis*) selected for data collection were between 6 to 8 years old. Samplings were conducted from June 2019 until February 2020, while the work in the laboratory started in December 2019 and was completed in March 2020.

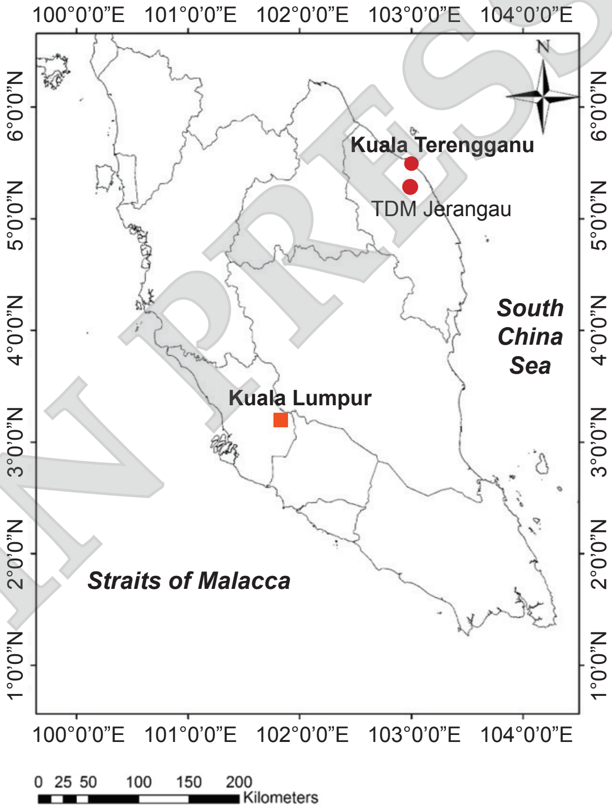

Figure 1. The location of the sampling site, TDM Jerangau (Ladang Jerangau) located in Terengganu state, Peninsular Malaysia.

Extraction of Arthropods from the Inflorescence

A total of 15 male and 15 female inflorescences were selected for the arthropod collections. These 15 inflorescences consisted of five pre-anthesis, five anthesis and five post-anthesis inflorescences. Identification of the anthesis stage was conducted based on the morphological descriptions of the inflorescence by Forero *et al.* (2012). The selected inflorescences were bagged in individual plastic bags and extracted from the trees. The inflorescences were then taken to the field station for observation. For each inflorescence, only 50% of the spikelets (male inflorescence) and rachillae (female inflorescence) were separated from the stalk and kept in plastic containers before being dissected individually under a dissecting microscope (Leica DME, Leica Microsystem [SEA]

Pte. Ltd., Malaysia). All arthropods observed from the spikelets and rachillae were then transferred into individual vials filled with a 70% ethanol solution and brought back to Universiti Malaysia Terengganu (UMT) for further identification in the laboratory. The arthropods were observed under a light microscope (CH20, Metric Optics Sdn. Bhd., Malaysia) in the General Biology Laboratory, UMT, and identification was conducted to the lowest taxonomic category possible, by referring to Gullan and Cranston (2014), Halim *et al.* (2017) and Norman *et al.* (2017).

Rearing of Larvae

Other than the adult individuals, larvae were also collected from the male inflorescence. As species identification is difficult at the larval stage, the larvae and spikelet were kept in the plastic container under ambient conditions in the General Biology Laboratory, UMT, until the larvae emerged into adults (approximately one week). The larvae were monitored daily and the adults that emerged were taken from the containers and observed under a dissecting microscope (Leica DME, Leica Microsystem [SEA] Pte. Ltd., Malaysia) for species identification.

Trappings of the Floral Visitors and Observations of Pollen Load

A modified bottle trap (*Figure 2*) was set up to capture the visitors of five male and female inflorescences (a trap each). Trappings were conducted for three days (anthesis day 3-5) for the male and two days (anthesis day 2-3) for the female inflorescence, during their peak anthesis time. The traps were installed at 1000 hr and checked regularly until 1100 hr for the trapped visitors, where we usually observed a high abundance of visitors at the oil palm inflorescence during this period. The trapped visitors were extracted from traps using forceps and transferred into a 1.5 mL centrifuge tube filled with 1.0 mL of 70% ethanol solution. The tubes were then taken to the laboratory for further analysis. In the laboratory, the tubes were shaken to separate the pollen grains from the visitors' bodies. For each tube, 0.5 μL of the solution was pipetted using a micropipette, then placed on a hemocytometer slide and covered with a cover slip. Pollen grains were observed under a light microscope attached to an eyepiece camera (Dino-eye AM 423X, Anno Electronics Corporation, Taiwan) with 70x magnification up to a maximum observation at 2800x. The pollen grains were grouped as either conspecific (*i.e.*, pollen grains of *E. guineensis*) or heterospecific (*i.e.*, pollen grains other than *E. guineensis*). For each vial, the procedure was repeated 10 times, thus the number of pollen grains was counted from 5 μL of the ethanol solution.

Figure 2. A bottle trap was set up to catch the flower visitors of the male inflorescence. The bottom part of the plastic bottle was removed to attach it to the inflorescence. The bottles used were approximately 300 mm long and 90 mm in diameter. Trapped individuals were extracted carefully from the open tip (25 mm in diameter) using long forceps.

Statistical Analysis

The diversity of arthropods collected from the inflorescence was calculated using the Shannon formula (H'), generated from PAST (Paleontological Statistics Software) ver. 3.26 statistical software. The frequency was used to compare the distribution of arthropods and tested with Pearson's Chi-square test (Yates correction was applied when small sample size was involved, *i.e.*, df = 1). For the non-normally distributed data of pollen loads, the paired Wilcoxon signed-rank test was used to compare the number of conspecific and heterospecific pollen loads of the floral visitors, while the Kruskal-Wallis test was conducted to compare the pollen loads between the visitors. All analyses were conducted using IBM Statistical Package for Social Science (SPSS) version 23.

RESULTS

Diversity of Arthropods Collected from Oil Palm Inflorescence

In total, 1969 arthropod individuals from three classes; Insecta, Arachnida and Diplopoda were collected from the oil palm inflorescences (*Figure 3, Table 1*). Male inflorescence recorded significantly (χ^2=1161.07, df=1, p<0.001) higher number of individuals (88%) as compared to the female inflorescence (12%). However, the total number of taxa recorded between the male and female inflorescence was found to be similar, with three taxa for the male and seven taxa for the female inflorescence (χ^2=1.70, df=1, p>0.05).

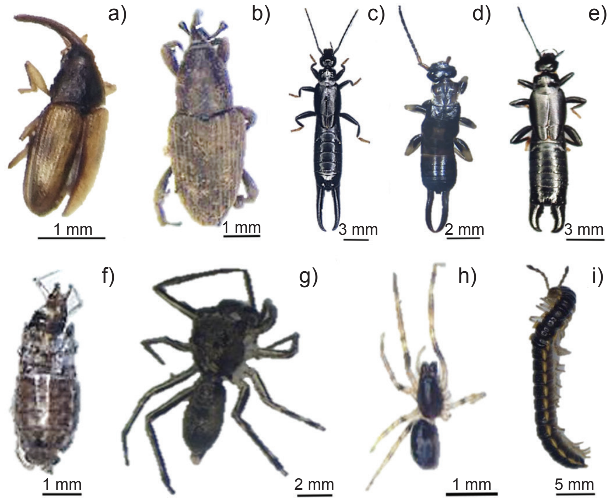

Figure 3. The arthropods collected from the oil palm inflorescence at Ladang Jerangau, TDM Plantation Hulu Terengganu. (a) Elaeidobius kamerunicus, *(b) Weevil, (c)* Chelisoches morio, *(d) Earwig 1, (e) Earwig 2, (f) Bug (nymph), (g) Spider 1, (h) Spider 2, (i)* Anoplodesmus saussurii.

For the male flower, *E. kamerunicus* (oil palm weevil) represented 98% of the total individuals collected (χ^2=3310.55, df=2, p<0.001), while the other individuals were from two unidentified earwig taxa. The Shannon diversity index (H') for these arthropods was 0.09. Meanwhile, the seven arthropod taxa recorded for female inflorescence consisted of four insect taxa from the order Coleoptera (beetles and weevils), Dermaptera (earwigs) and Hemiptera (true bugs), while the other three taxa consisted of two spiders and a millipede. Of these, *Chelisoches morio* (black earwig) significantly recorded the highest number of individuals which represented approximately 61% of the total number of individuals collected from the female inflorescence (χ^2=751.89, df=6, p<0.001). The Shannon diversity index (H') of the arthropods was 0.82. The Pearson Chi-Square test indicated a significant interaction in the number of arthropods collected and the anthesis stages (χ^2=929.13, df=2, p<0.001), in which the highest individuals were recorded for the male inflorescence at anthesis (n=1627) and the post-anthesis female inflorescence (n=110).

For the male inflorescence, a total of 861 larvae were collected from two insect taxa; *E. kamerunicus* and Fungus gnat (*Figure 4, Table 2*). The majority of the larvae collected were

TABLE 1. NUMBER OF INDIVIDUAL COLLECTED FROM OIL PALM INFLORESCENCES ACCORDING TO ANTHESIS STAGE

Class/Order	Family	Taxa	Male (N=15)				Female (N=15)			
			Pre-anthesis (n=113)	Anthesis (n=1 627)	Post-anthesis (n=1)	Total (n=1 741)	Pre-anthesis (n=36)	Anthesis (n=82)	Post-anthesis (n=110)	Total (n=228)
Insecta/ Coleoptera[α]	Curculionidae	*Elaeidobius kamerunicus*	88	1 623	1	1 712	1	3	1	5
		Weevil	0	0	0	0	1	0	0	1
Insecta/ Dermaptera[β]	Chelisochidae	*Chelisoches morio*	0	0	0	0	31	66	79	176
		Earwig 1	0	4	0	4	0	0	0	0
		Earwig 2	25	0	0	25	0	0	0	0
Insecta/ Hemiptera[ε]	-	Bug	0	0	0	0	2	3	26	31
Arachnida/ Araneae[β]	Salticidae	Spider 1	0	0	0	0	1	4	4	10
	Corinnidae	Spider 2	0	0	0	0	0	1	0	1
Diplopoda/ Polydesmida[δ]	Paradoxosomatidae	*Anoplodesmus saussurii*	0	0	0	0	0	5	0	5

Note: [α] Herbivore (pollen, nectar and tissue feeding); [β] Carnivore (predator); [ε] Herbivore (plant sap); [δ] Detritivore; N = Number of inflorescences observed; n = number of arthropod individuals.

from the post-anthesis inflorescence (83%) as compared to the other two stages (χ^2=996.25, df=2, p<0.001). From these, 57% emerged into adults *E. kamerunicus* (488 individuals) and Fungus gnat (six individuals).

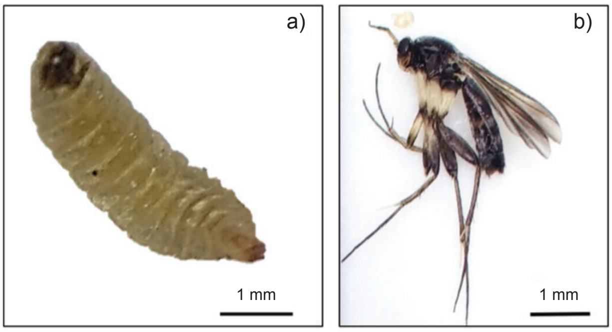

Figure 4. (a) Larvae of Elaeidobius kamerunicus *and (b) An adult of the Fungus gnat.*

Diversity of Insect Visitors to the Oil Palm Inflorescence

A total of 220 insect individuals were trapped while visiting the oil palm inflorescence (*Table 3*). The female inflorescence recorded significantly (χ^2=86.57, df=1, p<0.001) lower number of individuals (41 individuals) as compared to the male inflorescence (179 individuals). Apart from *E. kamerunicus* and Earwig 1 which were recorded earlier, seven additional insect taxa (*Figure 5*) were captured from two different Orders; five taxa from the Order Hymenoptera and two taxa from the Order Diptera. From the total nine taxa captured, seven and six taxa were recorded for male and female inflorescence respectively, in which only *E. kamerunicus*, Earwig 1, *Dolichogenidea metesae* (braconid wasp) and Fruit fly 1 were recorded for both inflorescences. Not only that, *E. kamerunicus* was also the most common weevil captured which represented 63% of the total captures for both females (χ^2=81.32, df=5, p<0.001) and males (χ^2=456.50, df=6, p<0.001) inflorescences. Fruit fly 1 was the second highest capture, in which the captures for male inflorescence (60 individuals) were significantly higher (χ^2=52.69, df=1, p<0.001) than the captures for the female inflorescence (seven individuals).

Pollen Load of the Arthropods Visiting the Oil Palm Inflorescence

From the total number of individuals trapped, only a single individual of *D. metesae* visiting the female inflorescence and 20 individuals (17 of Fruit fly 1, and three of *E. kamerunicus*) visiting the male inflorescence were negative for pollen load and

TABLE 2. NUMBER OF ADULT INDIVIDUALS EMERGED FROM LARVAE COLLECTED FROM THE OIL PALM INFLORESCENCES FOR EACH ANTHESIS STAGE

Order/ Family	Taxa	Common name	Anthesis stages			
			Pre-anthesis (N=2)	Anthesis (N=143)	Post-anthesis (N=716)	Total (N=861)
Coleoptera/Curculionidae	*Elaeidobius kamerunicus*	Oil Palm Weevil	2	54	432	488
Diptera	-	Fungus gnat	0	4	2	6

Note: N = number of larvae reared

TABLE 3. THE LIST AND ABUNDANCE OF INSECTS TAXA VISITING THE OIL PALM INFLORESCENCES

Order	Family	Taxa	Number of individuals	
			Male (N=179)	Female (N=41)
Coleoptera$^{\alpha}$	Curculionidae	*Elaeidobius kamerunicus*	113	26
Dermaptera$^{\beta}$	-	Earwig 1	2	2
Hymenoptera$^{\beta}$	Formicidae	*Anoplolepis gracilipes*	-	3
		Polyrhachis sp.	1	-
	Ichneumonidae	*Buysmania oxymora*	1	-
	Braconidae	*Dolichogenidea metesae*	1	2
	-	Wasp	1	-
Diptera$^{\gamma}$	Drosophilidae	Fruit fly 1	60	7
	-	Fruit fly 2	-	1

Note: $^{\alpha}$ Herbivore (pollen, nectar and tissue feeding); $^{\beta}$ Carnivore (predator); $^{\gamma}$ Herbivore (various plant materials); N = Number of visitors

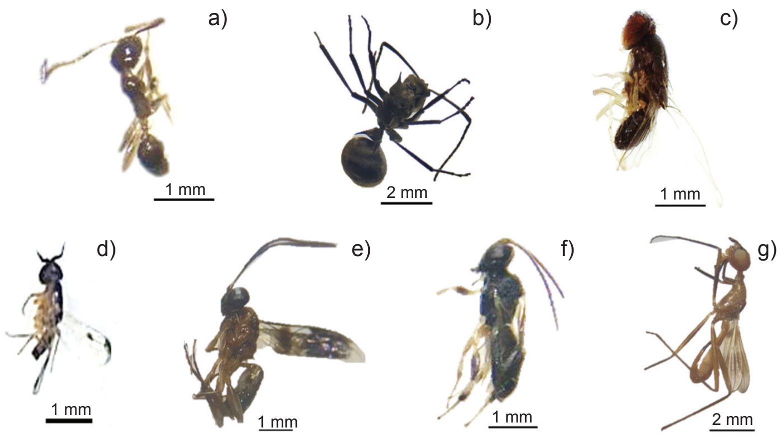

Figure 5. (a) Anoplolepis gracilipes, *(b)* Polyrhachis *sp., (c) Fruit fly 1, (d) Fruit fly 2, (e)* Buysmania oxymora, *(f)* Dolichogenidea metesae *and (g) Wasp.*

TABLE 4. NUMBER (MEAN±SE) OF POLLEN GRAINS CARRIED BY THE INSECTS CAPTURED VISITING THE OIL PALM INFLORESCENCE AT LADANG JERANGAU TDM PLANTATION

Taxa	Male inflorescence		Female inflorescence		
	Conspecific	N	Conspecific	Heterospecific	N
*Elaeidobius kamerunicus****	36.05±13.98^{ab}	110	13.31±6.99	0.54±0.30	26
Earwig 1*	7.50±5.00^{bc}	2	5.00±5.00	2.00±0.00	2
Anoplolepis gracilipes	-	-	2.50±0.50	0.00±0.00	2
Polyrhachis sp.	15.00±0.00	1	-	-	-
Buysmania oxymora	2.00±0.00	1	-	-	-
Dolichogenidea metesae	89.00±0.00	1	3.50±1.50	0.00±0.00	2
Wasp	1.00±0.00	1	-	-	-
Fruit fly 1**	7.40±2.02^{c}	43	8.86±3.54	0.29±0.29	7
Fruit fly 2	-	-	2.00±0.00	0.00±0.00	1

Note: For visitors to the male inflorescence, the different lowercase letter indicates a significant difference in the mean number of conspecific pollen loads between *E. kamerunicus*, Earwig 1 and Fruit fly 1 from multiple comparisons (stepwise step-down method) following significant result at $p<0.001$ of the Kruskal-Wallis test. For visitors to the female inflorescence with conspecific and heterospecific pollen loads, the Wilcoxon signed-rank test conducted indicates: *no significant difference, **significant at $p<0.05$ and ***significant at $p<0.001$ in the number of grains between the two pollen types; N = Number of individuals observed

thus were excluded from further analyses. A total of 159 insects visited the male inflorescence carrying only the conspecific grains (*Table 4*). Of these, an individual of *D. metesae* recorded the highest number of grains (89 grains), while *E. kamerunicus* recorded the second highest number (mean±SE) of pollen load with 36.05 ± 13.98 grains. Further analysis revealed that the mean number of pollen loads carried by *E. kamerunicus*, Earwig 1 and Fruit fly 1 were significantly different (Kruskal-Wallis test, H=17.97, df=2, $p<0.001$).

Four pollen types were recorded from the 40 individuals visiting the female inflorescence which consisted of the conspecific pollen and three unidentified types (the heterospecific pollen). Insect visitors from the six taxa captured visiting the female inflorescence were found with conspecific pollen loads, in which *E. kamerunicus* carried the highest number of grains (13.31 ± 6.99). Further analysis showed that the mean number of pollen loads carried by individuals across the six taxa was similar (Kruskal-Wallis test, H=3.131, df=5, $p=0.680$). In addition, *Anoplolepis gracilipes* (yellow crazy ant), *D. metesae* and Fruit fly 2 only carried the conspecific pollen grains on their bodies.

In contrast, insects from only three taxa (*E. kamerunicus*, Fruit fly 1 and Earwig 1) that visited the female inflorescence were found carrying the heterospecific pollen loads. Earwig 1 carried a significantly higher number of grains (2.00 ± 0.00) as compared to the other two taxa (Kruskal-Wallis test, H=7.055, df=2, $p=0.029$). Only *E. kamerunicus* (Wilcoxon signed-rank test, $z=4.475$, $p<0.001$) and Fruit fly 1 (Wilcoxon signed-rank test, $z=2.735$, $p=0.018$) however were found to show significantly higher conspecific rather than heterospecific pollen loads. While for Earwig 1, the conspecific and heterospecific pollen load was not significantly different (Wilcoxon signed-rank test, $z=0.447$, $p=0.655$). Between the three taxa that visited both

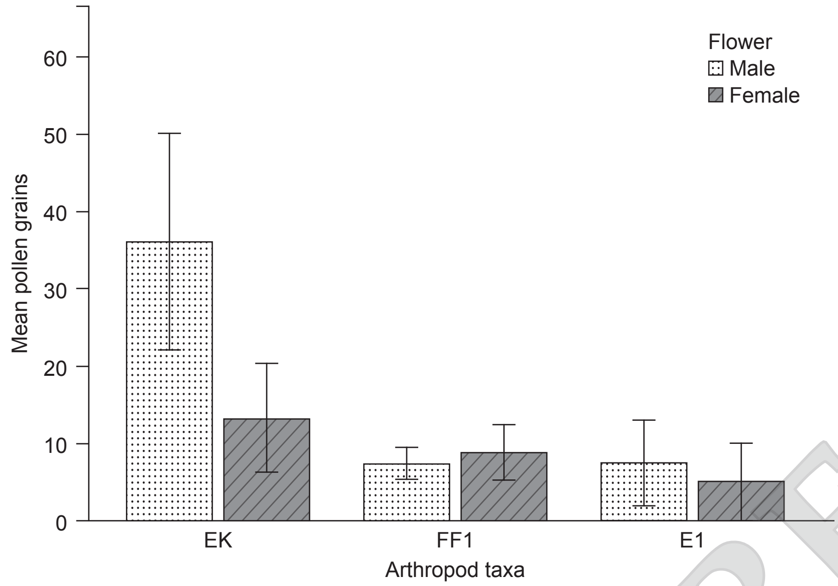

Figure 6. Mean of the conspecific pollen load for the three insects that visited both the male and female oil palm inflorescence. Error bars indicate a 95% confidence interval. EK = Elaeidobius kamerunicus *(male inflorescence = 110 individuals and female inflorescence = 26 individuals), FF1 = Fruit fly 1 (male inflorescence = 43 individuals and female inflorescence = 7 individuals), E1 = Earwig 1 (male inflorescence = 2 individuals and female inflorescence = 2 individuals).*

male and female inflorescences (*D. metesae* was excluded for this comparison because only an individual was caught at the male inflorescence), only *E. kamerunicus* carried a significantly higher number of conspecific pollen grains (Mann-Whitney test, U=792.500, $p < 0.001$) while visiting the male than the female inflorescence (*Figure 6*).

DISCUSSION

The present study reported a total of 14 insect taxa, two spiders and a millipede from the oil palm inflorescence (*Tables 1, 2* and *3*). From these, nine taxa were recorded for male inflorescence while 12 taxa were recorded for female inflorescence. Although male inflorescence recorded a higher abundance of arthropods, the species richness however was low (only four taxa including a fly taxon at the larval stage), although trappings yielded higher richness (seven taxa). Female inflorescence, in contrast, recorded an almost equal arthropod richness with seven and six taxa from collected and trapped individuals, respectively. However, the arthropod collected at this flower was with much lesser abundance as compared to the male inflorescence. The higher abundance and richness of the insect visitors to the male oil palm inflorescence as compared to the female inflorescence (Egonyu *et al.*, 2021) was due to the strong anise-seed scent emitted by the inflorescence which attracted the insect visitors (Anggraeni *et al.*, 2013; Lajis *et al.*, 1985), as well as the availability of pollen grains as a food source (Sambathkumar and Ranjith, 2011; 2015; Syed, 1979).

Furthermore, the anthesis phase of the male inflorescence was also over a longer period than the female (Forero *et al.*, 2012); between 6-8 days for the male as compared to 3-5 days for the female observed at the study site, thus the food reward (pollen grains) was offered for a longer period for the visitors. Female inflorescence, on the other hand, emits a similar scent to attract visitors (Lajis *et al.*, 1985) but due to a lack of food sources, the insects stay on the inflorescence only briefly (Syed, 1979). Hence the availability of food and the scent emitted by the inflorescence regulate the movement of these visitors from male to female inflorescence (Anggraeni *et al.*, 2013; Sambathkumar and Ranjith, 2011). While at the male inflorescence, these visitors usually collected the pollen grains on their bodies, thus likely transferring the grains to the stigma while visiting the female inflorescence later to initiate pollination.

A higher diversity of insects in oil palm plantations was reported in Malaysia (*e.g.*, Siti Khairiyah *et al.*, 2013) and elsewhere (*e.g.*, Siregar *et al.*, 2016 in Indonesia), and insects collected specifically at the oil palm inflorescence (*i.e.*, the flower visitors) were usually associated with their role as pollinators. The number of insect taxa recorded in the present study indeed was very much lower as compared to more intensive documentation of the flower visitors such as by Rizali *et al.* (2019) and Egonyu *et al.* (2021) in Indonesia and Uganda, respectively. In contrast, Bazurto *et al.* (2018) despite conducting a year of trappings of oil palm insect pollinators from more than 800 palm trees in Colombia, they reported only two insect taxa. The diversity of insect visitors in the oil palm plantation was noted to be higher in the areas closer to natural habitat than the areas farther away (Egonyu *et al*., 2021), although earlier reports indicated no relation in the diversity of insect pollinators in oil palm plantations and its distance from the forest habitat (Mayfield, 2005). A high abundance of oil palm inflorescence also might attract the insects to forage in the plantation areas (Siregar *et al*., 2016).

Elaeidobius kamerunicus was the most predominant arthropod recorded for male inflorescence, in which adults were predominantly collected from the anthesising inflorescences, while its larvae were extracted from the post-anthesis inflorescence (*Table 2*). Moreover, a high abundance of this weevil was also captured at the female inflorescence, carrying high conspecific pollen grains on their bodies (*Table 4* and *Figure 6*). This weevil thus undoubtedly is the principal pollinator for the oil palm trees (Auffray *et al*., 2017; Kouakou *et al*., 2014; Melendez-Jacome *et al*., 2019; Sambathkumar and Ranjith, 2015; Syed, 1979) even in the tropical Asian region where it was introduced (Li *et al*., 2019; Syed *et al*., 1982; Yue *et al*., 2015). Mutualism between the oil palm trees and this weevil is further explained by the importance of male inflorescence for the weevil to complete its life cycle (Adaigbe *et al*., 2011).

The presence of predatory insects such as ants, wasps and earwigs, together with the two spider taxa recorded at the inflorescence, indicates potential predators of the insect pollinators (Bos *et al*., 2008; Muhammad Luqman *et al*., 2017; Panabang *et al*., 2017). A high abundance of these predatory arthropods; Earwig 2 at the pre-anthesis male inflorescence, *C. morio* at the anthesis and post-anthesis female inflorescence, and particularly the spiders which were only collected from the female inflorescence, is certainly a concern. Predation risk exists not only to the adult individuals but predation on larvae by the Earwig 1 was also documented (*Figure 7*) during the cataloguing of the arthropod samples. While Earwig 1 was noted as a predator of larvae, surprisingly it was also observed to carry the conspecific grains while visiting both male and female inflorescences and was thus also likely a pollinator (*Table 4* and *Figure 6*). Although no further investigation was made on the effect of these predatory arthropods on the pollination success of the oil palm trees in the study area, predation on larvae and adult *E. kamerunicus* might impose negative results on the fruit yield from its population reduction (Li *et al*., 2019; Muhammad Luqman *et al*., 2017).

Arthropod predators nevertheless are important natural biological control agents in oil palm plantations in Malaysia (Denan *et al*., 2020). For example, *C. morio* was found to predate heavily on the larvae of the coconut spike moth (*Tirathaba ruvifena*), one of the important insect pests of the oil palm tree (Zhong *et al*., 2016). Other than that, the presence of the parasitic wasp, *D. metesea*, together with the parasitoid wasp, *Buysmania oxymora*, suggested natural pest controlling activities at the study area particularly aimed at the other prominent pest of the oil palm tree, the bagworm, *Metisa plana* (Halim *et al*., 2017; Kamarudin and Arshad, 2016). Hence maintaining these arthropods in the oil palm plantation could minimise the use of pesticides for pest control, thus supporting sustainable agricultural practices.

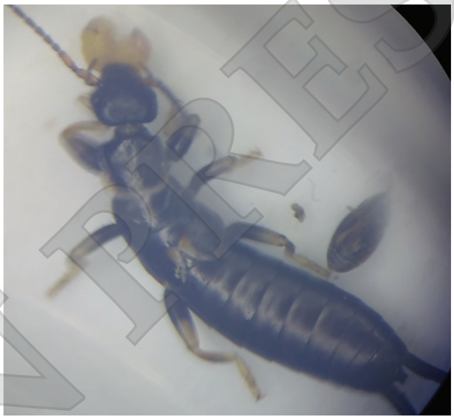

Figure 7. Predation on larvae by Earwig 1 was observed while conducting sample cataloguing.

A total of three fly taxa were noted in the study area, in which larvae of a single taxon were collected from the post-anthesis male inflorescence (*Figure 4* and *Table 2*), indicating this inflorescence acted as a breeding site of the fly. For the coleopteran and dipteran insect pollinators, it is common for the larvae to develop in the decomposed male inflorescence, in which the insects collected pollen grains on their bodies during oviposition at the anthesising inflorescence (Sakai, 2002). For the dipteran flies associated with the oil palm inflorescence, however, their contribution to pollination of the oil palm trees is still not fully understood (Mayfield, 2005; Rizali *et al*., 2019; Sambathkumar and Ranjith, 2011). In the present study, the Fruit fly 1 which was captured at a notably higher abundance at the male inflorescence (*Table 4* and *Figure 6*), was found with high conspecific pollen loads on their bodies, thus showing its importance as pollen vectors for the oil palm trees. Not only that, Fruit fly 2, together with *A. gracilipes* and *D. metesae*, were also found with conspecific pollen grains on their bodies while visiting the female inflorescence (*Table 4*), indicating their potential to contribute to the pollination of the inflorescence. Unfortunately, *A. gracilipes* was known to be an invasive ant and predates on other ant species in agroecosystem habitats (Bos *et al*., 2008; Sinu *et al*., 2017).

One of the other noteworthy results in the present study was the record of black earwig *C. morio* collected from the oil palm inflorescence, which is a new locality report for this species in Peninsular Malaysia. This species was previously recorded only from Selangor, Kuala Lumpur and Penang Island (Kamimura *et al.*, 2016a). In Penang Island, earwig fauna was reported to occupy almost all environmental conditions and vegetation types, including plantations. Another interesting finding was five individuals of a polydesmid millipede, *Anoplodesmus saussurii*, which were collected at the anthesising female inflorescence (*Table 1*). Millipedes, in general, are detritivores which consume decaying plant materials and have never been reported to feed on living plants. Millipedes are usually found under the decaying litter layers (Decker and Tertilt, 2012), or in the soil, as reported by Sakiah *et al.* (2017) and Jhon *et al.* (2019) in oil palm plantations, which help in the mixing of the decomposing materials into the soil layers. As for *A. saussurii*, it was reported to be endemic to Sri Lanka (De Zoysa *et al.*, 2016), but potentially is more widespread with more deep observations being made with more published documentation available (Decker and Tertilt, 2012; Golovatch and Stoev, 2013). In Singapore, this species is commonly found aggregated in a large numbers (Decker and Tertilt, 2012), hence the few individuals collected from the inflorescence in the present study could be accidental. Information on the taxonomy, distribution and ecology of the earwigs (Kamimura *et al.*, 2016a; 2016b) and millipedes (Golovatch and Stoev, 2013; Likhitrakarn *et al.*, 2016; Moseley, 2006) in Peninsular Malaysia is currently limited, thus the observations reported in this study are valuable to add more knowledge of these inconspicuous arthropod faunas.

The present study documented a high diversity of arthropods in the oil palm plantation, indicating that this invertebrate fauna is an important component in this agricultural area. Arthropod fauna, particularly the insects, provides important ecosystem services such as pollination, biological control (through predation, herbivory and parasitism), food provisioning and decomposition of organic matters, although these could be under-represented (Noriega *et al.*, 2018). In agricultural ecosystems, knowledge of insect pollinators is biased towards charismatic taxa such as the lepidopteran, hymenopteran and coleopteran insects, while the functional roles provided by other insects are still not fully understood (Hortal *et al.*, 2015). Results in our study, for example, revealed that several predatory insects have the potential to act as pollinators for the oil palm trees. Moreover, although several herbivorous insects were recorded, we did not find any evidence to suggest that these insects caused a negative impact on the inflorescences such as damage to the floral tissues. We are aware that this observation is based on small sample size, but we believe that the findings from this study contribute significantly to the current knowledge of these important insect communities in the agricultural area. This may lead to better agricultural and management practices that support greater biodiversity in this important ecosystem.

CONCLUSION

Arthropod fauna of the oil palm inflorescence at Ladang Jerangau Terengganu consisted of 17 taxa, with insects (14 taxa) being the most predominant fauna recorded. Other than to feed on the floral source (pollen) of the oil palm inflorescence, several insect taxa were potentially preying on other insects at the inflorescence. Apart from *E. kamerunicus*, an unidentified fly taxon was also observed to oviposit at the male inflorescence, and predation on the larvae of these two insects by the earwig was witnessed in this study. The palm weevil, *E. kamerunicus* was again detected as the main pollinator of the oil palm tree, by collecting the pollen grains on their bodies while aggregating at the male inflorescence, followed by transporting the conspecific grains to the female inflorescence. In addition, the potential role of other insect taxa as pollinators for the oil palm trees were also detected from their conspecific pollen loads while visiting the male inflorescence (*i.e.*, an unidentified earwig, *A. gracilipes*, *D. metesae* and 2 unidentified flies), as well as while visiting the female inflorescence (*i.e.*, *Polyrhachis* sp., *B. oxymora* and *D. metesea*). This study also reported the first record of *C. morio* in Terengganu, which is also a new locality record of this earwig taxon in Peninsular Malaysia. We suggest that more detailed studies be conducted on these elusive insects, in order to increase the current understanding of their ecological roles in oil palm plantations.

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