https://doi.org/10.17576/serangga-2024-2903-07

RECORDS ON ANTHOPHILOUS INSECTS AS POLLINATORS OF *Elaeis guineensis* JACQ. (ARECALES: ARECACEAE) IN MALAYSIA

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Received: 11 November 2023; Acceptance: 23 June 2024

ABSTRACT

The potential role of anthophilous insects as pollinators is determined by their interactions with inflorescences. Thus, observation on the anthophilous insects was conducted at Ladang Jerangau, Terengganu, Malaysia to identify the potential pollinators of oil palm, *Elaeis guineensis* Jacq. Anthophilous insects from male oil palm inflorescences were recorded continuously throughout its anthesis period using digital video cameras, taken in 2019 for a total of 18 days. Data were recorded from four inflorescences, and the legitimacy of each visitation by the insects was determined based on the point of contact at the inflorescences. A total of 16 species of insects were recorded from the video observations. Amongst these species, *Elaeidobius kamerunicus* was the most important pollinator (VII = 1.6 x 10^5) given their frequent legitimate visits (656.19±464.37), and they collected abundant pollen (7205.45+2723.38) on their bodies. Moreover, males (VII = 2.5 x 10^5) of this species were found to be more important pollinators than the females (VII = 6.5 x 10^4) on the basis of their total pollen loads. Five other insects (*Pyroderces* sp., Dermaptera sp., *Anoplolepis gracilipes*, *Eocanthecona* sp. and *Thrips hawaiiensis*) were also found to exhibit regular legitimate visits (>30 visits) and are also likely pollinators. Video recordings thus provide a better understanding of insect-flower interactions in oil palm plantations. This knowledge is useful for supporting biodiversity-friendly management of the insects, which will benefit the oil palm industry in Malaysia.

Keywords: Legitimate visit, pollen collection, visitation frequency, *Pyroderces* sp., *Thrips hawaiiensis*

ABSTRAK

Potensi peranan serangga antofilous sebagai pendebunga ditentukan oleh interaksi mereka dengan bunga. Maka, pemerhatian ke atas serangga antofilus telah dijalankan di Ladang Jerangau, Terengganu, Malaysia untuk mengenalpasti potensi pendebunga bagi kelapa sawit, *Elaeis guineensis* Jacq. Serangga antofilous daripada bunga jantan kelapa sawit telah direkodkan secara berterusan sepanjang tempoh antesisnya menggunakan kamera video digital, yang diambil pada tahun 2019 untuk sejumlah 18 hari. Data telah direkodkan daripada empat bunga, dan kesahihan setiap lawatan oleh serangga telah ditentukan berdasarkan titik sentuhan pada bunga. Sebanyak 16 spesies serangga telah direkodkankan daripada pemerhatian video. Di antara spesies ini, *Elaeidobius kamerunicus* adalah pendebunga yang paling penting (VII = 1.6 x 10^5) memandangkan lawatan sah mereka yang kerap (656.19±464.37) dan mereka mengumpul debunga yang banyak (7205.45+2 723.38) pada badan mereka. Selain itu, jantan (VII = 2.5 x 10^5) spesies ini didapati sebagai pendebunga yang lebih penting daripada betina (VII = 6.5 x 10^4) berdasarkan jumlah beban debunga mereka. Lima serangga lain (*Pyroderces* sp., Dermaptera sp., *Anoplolepis gracilipes*, *Eocanthecona* sp. dan *Thrips hawaiiensis*) juga didapati mempamerkan lawatan yang sah secara kerap (>30 lawatan) dan juga berkemungkinan menjadi pendebunga. Rakaman video dengan itu memberikan pemahaman yang lebih baik tentang interaksi bunga serangga dalam ladang kelapa sawit. Pengetahuan ini berguna untuk menyokong pengurusan mesra biodiversiti bagi serangga, yang akan memberi manfaat kepada industri kelapa sawit di Malaysia.

Kata kunci: Pelawat sah, pengumpulan debunga, frekuensi lawatan, *Pyroderces* sp., *Thrips hawaiiensis*

INTRODUCTION

Elaeis guineensis Jacq. or the African oil palm, is of African origin, and widely cultivated in the tropical areas of Southeast Asia, particularly in Malaysia and Indonesia, due to its economic value (Murphy et al. 2021). The palm tree is monoecious, and produces distinguishable unisexual inflorescences in alternating cycles to minimise the probability of self-pollination amongst the inflorescences of the same tree (Adam et al. 2011). In contrast to female inflorescence, male inflorescence contains long and cylindrical-shaped spikelets, which are borne atop long peduncles. In earlier years, the lack of pollinators had generated a theory that the palm tree is an anemophilous (pollinated by wind) rather than entomophilous (pollinated by insects) plant (Hardon & Turner 1967; Turner 1978). Although oil palm inflorescences show many characteristics of wind-pollinated plants such as syncarpy, polyspermy, with smooth pollen grains and enlarged stigmatic surface, these traits are also shown by the beetle-pollinated inflorescences (Willmer 2011). However, further studies concluded that the palm tree is pollinated by insects, predominantly coleopteran weevils (Appiah & Agyei-Dwarko 2013; Li et al. 2019; Melendez & Ponce 2016).

Oil palm inflorescences release a large amount of the volatile compound estragole (Lajis et al. 1985; Misztal et al. 2010), which produces an anise seed-like odour to attract insects, particularly the African oil palm weevil, *E. kamerunicus* (Anggraeni et al. 2013; Syed 1979). The variation in the *E. kamerunicus* population at male and female oil palm inflorescences was concluded to be influenced by the odour-releasing strategy of these inflorescences. *Elaeidobius kamerunicus* congregates at anthesising male inflorescences, which usually undergo anthesis earlier than female inflorescences, due to estragole emission during this phase. When male inflorescences start to wilt and estragole emission declines, female inflorescences begin to undergo anthesis and emit farsenol, which attracts weevils towards anthesising female inflorescences (Anggraeni et al. 2013).

Apart from *E. kamerunicus*, other insects such as dipterans, hymenopterans and the lepidopterans, are amongst the most dominant groups visiting the inflorescences of cultivated palm trees (Egonyu et al. 2021; Rizali et al. 2019). In addition to being attracted to odour, these anthophilous insects (i.e. insects that frequent the inflorescences because they feed on, live within, or are simply attracted to inflorescences) utilise oil palm inflorescences as their foraging sites; either for floral resources or to prey on other insects present at inflorescences, and as their living and breeding sites (Li et al. 2019; Muhammad Luqman et al. 2017; Rizali et al. 2019; Yue et al. 2015). However, given that male and female oil palm inflorescences offer different sources, some insects visit or are present only at male or female inflorescences (Egonyu et al. 2021; Rizali et al. 2019). For example, the insects present at male inflorescences usually feed on pollen grains and soft floral parts, but might not visit female inflorescences due to the lack of food sources (Syed 1979; Syed et al. 1982). Hence, not all of these insects are pollinators of oil palm trees.

Although previous studies typically reported only *E. kamerunicus*., *Pyroderces* sp. (cosmeth moth) and *Thrips hawaiiensis* (Hawaiian flower thrips) as the pollinators of oil palm trees in Malaysia (Syed et al. 1982; Wahid & Kamarudin 1997; Yue et al. 2015), a recent study in Indonesia reported that other insects visiting the oil palm inflorescences also exhibit a pollinator potential by carrying oil palm pollen grains on their bodies (Lumentut et al. 2022). Pollen load examination nevertheless requires extracting insects from oil palm plantations. Although intensive trappings might generate conclusive findings from a larger data set, it could also negatively impact insect population size in plantations. Conversely, time-lapse video recordings allow *in-situ* observations of the interaction between anthophilous insects and inflorescences (Edwards et al. 2015) with less disruption to the insect community (Bonelli et al. 2020). Insect activities at oil palm inflorescences are crucial in the pollination of the palm trees (Auffray et al. 2017). For example, insect activities at male inflorescences determine the potential of insects to collect pollen grains on their bodies while at the inflorescences. The odour emitted by oil palm inflorescences regulate the movement of these insects between inflorescences (Anggraeni et al. 2013), thus likely moving pollen grains from male to female inflorescences. These insects hence act as pollinators in oil palm plantations.

Oil palm inflorescences are visited by a diverse group of insects (Egonyu et al. 2021; Rizali et al. 2019). In Malaysia however, other than that of the introduced *E. kamerunicus*, little is known about the role of the native pollinators; *Pyroderces* sp. and *T. hawaiiensis* in the pollination of oil palm trees. The contributions of native insect pollinators have been reported to increase oil palm fruit set (Montes Bazurto et al. 2018; Wahid & Kamarudin 1997), indicating the vital role of native insects as complementary pollinators. Thus, this study presents novel insights into the importance of anthophilous insects in commercial plantation of *E. guineensis* in Peninsular Malaysia from observations made through video recordings.

MATERIALS AND METHODS

Study Site

This study was conducted in 2019 at an oil palm plantation owned by Terengganu Development Management (TDM) Sdn. Bhd., namely, Ladang TDM Jerangau (hereafter Ladang Jerangau), Terengganu, Malaysia. In 2017, all TDM oil palm plantations in Terengganu including Ladang Jerangau, were certified as Malaysia Sustainable Palm Oil (MSPO). Ladang Jerangau

(4°57'45"N 103°9'59"E) is located in Hulu Terengganu District, which is situated in the interior Terengganu state (Figure 1). The total area of this plantation is approximately 390 ha, which also includes office buildings and staff houses.

Figure 1. Location of the study site (pointer) in Terengganu state, Peninsular Malaysia

Video Recording

Recordings of the floral visitors to *E. guineensis* trees were conducted for 18 days in 2019. Video recordings were performed in two separate sessions; 8 days for the first session between January and February, and 10 days for the second session between June and September. Recordings were conducted on four male inflorescences from four different palm trees of 6-8 years old (DxP material) with inflorescences located between 2-3 m from the ground. For each inflorescence, four units of digital video cameras (Sony Handycam FDR-AXP55, Japan) were used alternately, starting from 1100 hr on the first day of anthesis, until 1000 hr of the fifth day of anthesis. The flower anthesis was determined in reference to Forero et al. (2012). The first day of anthesis for male inflorescences was determined when approximately 20% of the spikelets started to produce florets with visible yellowish pollen grains. A camera was then set up inside a custom-made wooden box to record the lateral view of the inflorescences at a distance of 0.5-1.0 m from the observed inflorescence (Figure 2). The cameras were tended to every 3 hours throughout the recordings, to replace the battery and memory card. On the fifth day of anthesis, when the video recording ceased, only approximately 10% of the spikelets had florets and fungi were visible on the mostly decomposed spikelets.

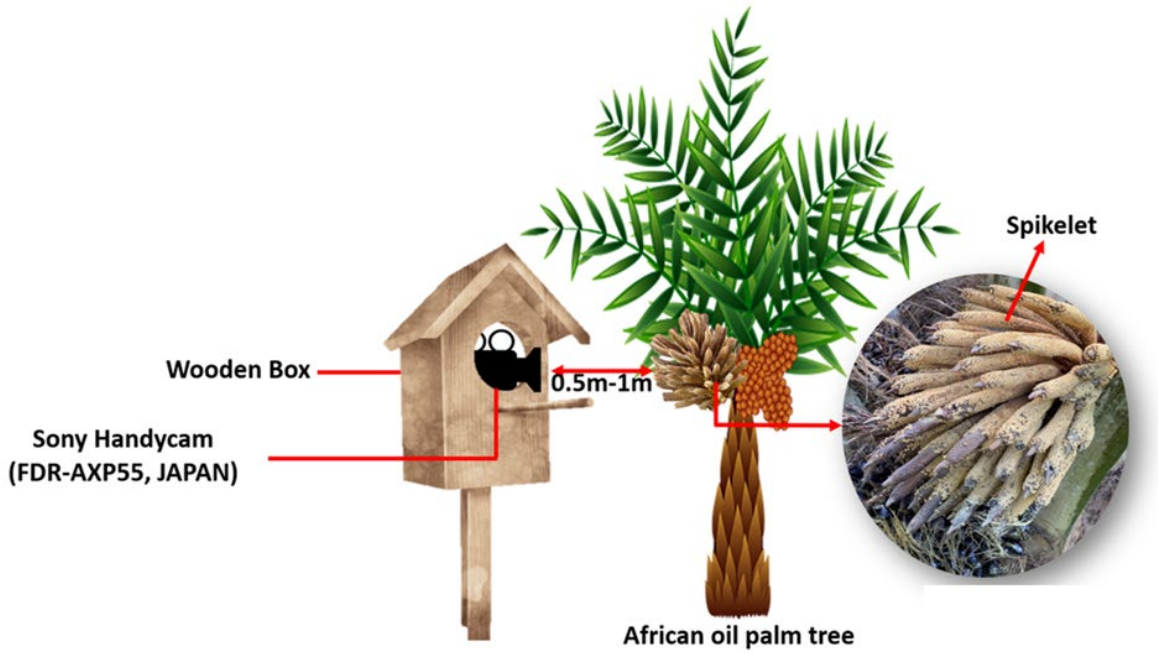

Figure 2. Graphical representation of the video recording conducted in Ladang Jerangau, Terengganu, to observe visitors of male oil palm inflorescences

Analysis of the Video Recording

The video footage was transferred from the memory cards to a computer and analysed by using Windows Media Player Version 12.0. As a result of camera malfunction, one of the inflorescences was recorded starting from the second day until the fourth day of anthesis. Therefore, the total recording hours of the four inflorescences was only 336 hours. The times of observations on insect pollinators through digital video recordings varied with goals and approaches (e.g. Bonelli et al. 2020; Gilpin et al. 2017; Pegoraro et al. 2020; Steen 2017). In the present study, the footage from only the first 5 min of every hour was analysed because the insects swamped at the inflorescences particularly during the peak anthesis stage (days 3 and 4 of recordings). Thus, the total hours of video footage observed was 28 hours. The identity of visitors, and the frequency of visitation were recorded from the footage. The visitors were identified by comparing the image from the footage with multiple sources such as websites, identification manuals and published materials (Halim et al. 2017; Norman et al. 2017) on insects in oil palm plantations, particularly in Malaysia, as well as with the insect individuals collected at the same sampling site in other studies. For visitation frequency, one visit was defined as when an individual insect contacted the spikelet until it left the frame, or until it moved to an opposite legitimacy point (i.e. from a legitimate to an illegitimate visit or vice versa) although it stayed in the frame. The legitimacy (legitimate or illegitimate) of the visit was determined by observing the point of contact by the insects on the spikelet. A visit was considered as legitimate when the insect touched the location with florets (which produced the pollen grains), whereas a visit was considered illegitimate when the insect touched elsewhere (Figure 3).

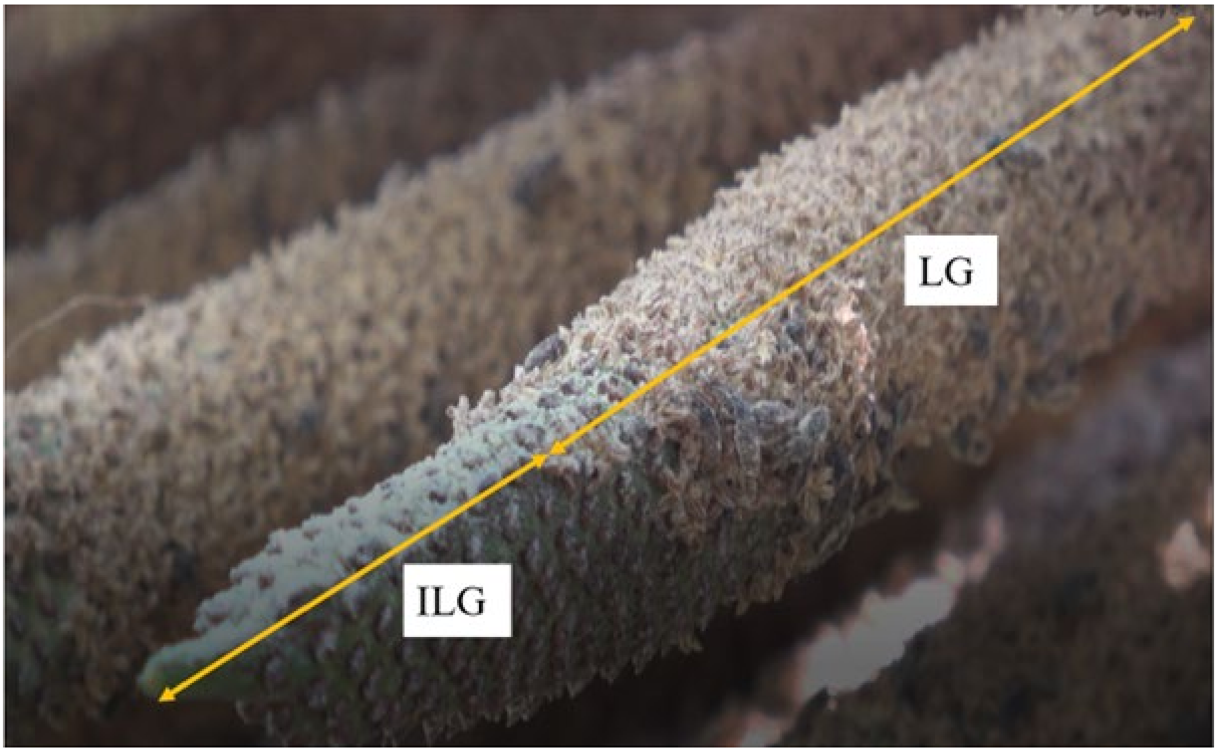

Figure 3. Point of contact by insect visitors on the spikelet to determine the legitimacy of a visit. A visit was considered as legitimate when the visitors contacted the spikelet with florets (LG) and as illegitimate when the visitors contacted the area without florets (ILG)

Data Analysis

The data recorded were analysed by using Paleontological Statistics (PAST) software version 4.04. Chi-square test was used for the comparison of the frequency (number of species) between insect orders and that (number of visits) between legitimate and illegitimate visits. Kruskal-Wallis test was conducted to compare visitation rates between visitors, and was conducted for species with more than 50 visits only. The visitation rate of each visitor was calculated by dividing the total number of visits with the total observation hours (Albano et al. 2009).

For determining the importance of insect species as pollen vectors, the visitor importance index (VII) was calculated for all species recorded visiting male oil palm inflorescences in Ladang Jerangau listed from both the video observations in the present study and from a previous study conducted by Nor Zalipah et al. (2024) by capturing insect visitors by using bottle traps at the same study site. The VII value of each species was determined with the formula modified from Ne'eman et al. (1999) by multiplying the means of the visitation rate, legitimate visits and total pollen load recorded for each species. This value then was divided by 10 000 for the standardisation of the final VII value.

The total pollen load for each insect species captured visiting male inflorescences was determined from Nor Zalipah et al. (2024) who recorded the pollen load by counting the number of pollen grains for each insect individual from only 5 µL of an ethanol solution. Pollen counts from the total 1.0 mL of ethanol solution in the centrifuge tube used to preserve the individual insect and its pollen grains were inferred from previous data to obtain the total pollen load. Each preserved sample of *E. kamerunicus* was examined under a dissecting microscope attached with eyepiece camera (Dino-eye AM 423X, Anno Electronics Corporation, Taiwan) to identify their sex in accordance with Muhammad Nasir et al. (2020). The Mann-Whitney test was then used to compare the mean of the total pollen loads for male and female *E. kamerunicus* individuals, to infer the effectiveness of pollen collection between the sexes of this weevil.

RESULTS

Insect Visitors

In this study, 16 insect species from seven orders were recorded; Hymenoptera, Coleoptera, Lepidoptera, Thysanoptera, Hemiptera, Dermaptera, and Diptera (Table 1). Apart from the five identified species, eight and three taxa were identified to only the order and genus levels respectively. Order Diptera recorded the highest number of species (five species), followed by Hymenoptera (three species). Meanwhile, three orders namely Lepidoptera, Dermaptera and Thysanoptera were represented by only a single species. The Chi-square test showed that there was no significant difference in the number of species between the seven insect orders (χ^2 = 5.864, df = 6, P>0.05).

In total, 11914 visits by these 16 insect species were recorded. The highest visitations were by *E. kamerunicus* which represented approximately 92 % of the total visitations with 10984 visits, whereas the lowest was by the Asian honey bee, *Apis cerana,* with only a single visitation. Five species in addition to *E. kamerunicus* registered more than 50 visitations. The Kruskal-Wallis test conducted on these six species (Figure 4) revealed no significant difference in the visitation rate (Mean±SE) between species (H = 8.365, df = 5, P=0.1349).

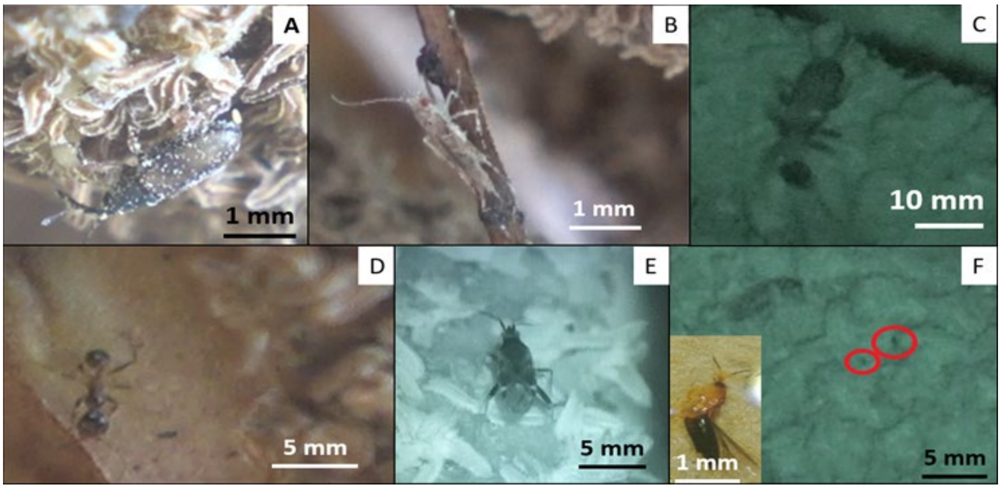

Figure 4. Photo of the six visitor species to male oil palm inflorescences with more than 50 visitations in Ladang Jerangau, Terengganu. A) *Elaeidobius kamerunicus*, B) *Pyroderces* sp., C) Dermaptera sp., D) *Anoplolepis gracilipes*, E) *Eocanthecona* sp., F) *Thrips hawaiiensis*.Inset photos in D and F show captured of respective species using sticky trap for another study at the same study site

Table 1. List of the visitors of male oil palm inflorescences in Ladang Jerangau, Terengganu, with their number of visitations. The visitation rate (Mean+SE) was determined from four inflorescences

Order	Family	Species	Common name	Total Visitation	Visitation Rate (Visit/Hour)
Coleoptera	Curculionidae	*Elaeidobius kamerunicus*	African oil palm weevil	10 984	343.35±258.73
		Metamasius hemipterus	West Indian cane weevil	2	0.10±0.06
Lepidoptera	Cosmopterygidae	*Pyroderces* sp.	Cosmeth moth	400	12.53±7.05
Dermaptera		Dermaptera sp.	Earwig	189	7.35±2.10
Hymenoptera	Formicidae	*Anoplolepis gracilipes*	Yellow crazy ant	119	4.00±2.54
		Diacamma sp.	Asian bullet ant	20	0.69±0.20
	Apidae	*Apis cerana*	Asian honey bee	1	0.03±0.03
Thysanoptera	Thripidae	*Thrips hawaiiensis*	Hawaiian flower thrips	59	1.94±1.19
Hemiptera	Pentatomidae	*Eocanthecona* sp.	Pentatomid bug	115	3.60±3.60
		Hemiptera sp. 1	True bug 1	2	0.06±0.06
		Hemiptera sp. 2	True bug 2	2	0.06±0.06
Diptera		Diptera sp. 1	Fly 1	6	0.19±0.09
		Diptera sp. 2	Fly 2	2	0.06± 0.06
		Diptera sp. 3	Fly 3	3	0.10±0.04
		Diptera sp. 4	Fly 4	2	0.16±0.09
		Diptera sp. 5	Fly 5	8	0.25±0.25

Visitation to the Inflorescences

Of the total visits recorded for all visitors (Table 2), 92% were legitimate (10980 visits) whereas only 8% (934 visits) were illegitimate (Chi-square test, χ^2 = 8470.88, df = 1, P<0.05). *Elaeidobius kamerunicus* was the species with the highest legitimate and illegitimate visits with 10499 and 485 visits, respectively. The Chi-square revealed a significant difference between the number of legitimate and illegitimate visits for seven species, whereas only a single species (Diptera sp. 1) showed no significant difference. Amongst these seven species, *E. kamerunicus* (96%), *Pyroderces* sp. (78%) and *T. hawaiiensis* (73%) were found to show significantly higher legitimate than illegitimate visits (Fig. 5). Meanwhile, the yellow crazy ant, *Anoplolepis gracilipes* had the highest percentage of illegitimate visits (82%). Of the other eight species, five had only the legitimate visits (*A. cerana*, Diptera sp. 2, Diptera sp. 3, Diptera sp. 4 and Diptera sp. 5) and two species had only illegitimate visits (Hemiptera sp. 1 and Hemiptera sp. 2). Meanwhile, the west Indian cane weevil (*Metamasius hemipterus*) showed an equal number (one visit) of legitimate and illegitimate visits.

Table 2. Number of legitimate and illegitimate visits of each visitor. The list is arranged in accordance with the highest to the lowest number of visitations

Species	Legitimate	Illegitimate	χ^2 value	*P* value
Elaeidobius kamerunicus	10499	485	4564.83	<0.05
Pyroderces sp.	311	89	61.61	<0.05
Dermaptera sp.	47	142	23.88	<0.05
Anoplolepis gracilipes	22	97	23.63	<0.05
Eocanthecona sp.	36	79	8.04	<0.05
Thrips hawaiiensis	43	16	6.18	<0.05
Diacamma sp.	1	19	8.10	<0.05
Diptera sp. 1	4	2	0.33	>0.05
Diptera sp. 5	8	0	NC	-
Diptera sp. 3	3	0	NC	-
Metamasius hemipterus	1	1	NC	-
Diptera sp. 2	2	0	NC	-
Diptera sp. 4	2	0	NC	-
Hemiptera sp. 1	0	2	NC	-
Hemiptera sp. 2	0	2	NC	-
Apis cerana	1	0	NC	-
Total	**10980**	**934**	**8470.88**	**<0.05**

Nc = Not calculated

Visitor Importance Index

A total of 21 insect species were recorded as visitors of male oil palm inflorescences in Ladang Jerangau, Terengganu from observations on video footage and the insect trappings (Table 3). The VII value however was calculated for only two species (*E. kamerunicus* and Dermaptera sp.) and not calculated for the other 19 species due to insufficient data. For *E. kamerunicus,* the total pollen load (Mean±SE) was 7205.45±2723.38 (n = 110 individuals). The Mann-Whitney test revealed a significant difference in the total pollen load between male and female weevils (U = 1208, P = 0.03), in which males had a higher number of grains (11121.43±5261.25, n =

56 individuals) than females (2901.852±480.89, n = 54 individuals). The VII calculated for the two species indicated that *E. kamerunicus* showed a higher value (1.6×10^5) than Dermaptera sp. (3.24). Furthermore, the VII value of male *E. kamerunicus* was higher at 2.5×10^5, whereas that of female was only 6.5×10^4.

DISCUSSION

In total, 21 insect species were listed as visitors of the male oil palm inflorescences in Ladang Jerangau, Terengganu (Table 3). Amongst these species, 16 were recorded in the video footage (Table 1), whereas five species were recorded in a previous study that captured the insect visitors at the same study site (Nor Zalipah et al. 2024). Only two species were found to be recorded through both observation methods. Several dipteran (five species) and hemipteran (two species) insects observed in the present study were too small and were thus difficult to detect in the video footage. The night footage further limited the features, such as colour, observable for species identification. Despite this slight setback, the observations on insects from the video recordings nevertheless added more knowledge to the current list of insects captured visiting male oil palm inflorescences at the study area.

Amongst the total 16 species observed from the video footage, *E. kamerunicus* was unsurprisingly found to be the most common visitor of male oil palm inflorescences in Ladang Jerangau, Terengganu (Table 1). Many studies have confirmed that this weevil is the primary pollinator of oil palm trees in Malaysia (Wahid & Kamarudin 1997; Wahid et al. 1988; Syed 1979; Syed et al. 1982). Elsewhere in Malaysia, the abundance of *E. kamerunicus* individuals at male oil palm inflorescences is highest during the peak anthesis day of the inflorescence, which is usually during third day of the anthesis, before decreasing on the fourth day onwards (Swaray et al. 2021). The higher number of visitation by *E. kamerunicus* and other insects to male oil palm inflorescences during the early stage of the anthesis phase is due to the higher abundance of pollen grains available on the spikelets (Yue et al. 2015) than towards the end of the anthesis phase, in which the spikelet started to shed pollen and fungi started to grow (Forero et al. 2012). Furthermore, as anthesis progressed, the amount of estragole released by male inflorescences increased, resulting in more *E. kamerunicus* individuals visiting to the inflorescences (Anggraeni et al. 2013).

Elaeidobius kamerunicus not only showed a high number of visits (Table 2), 96% (10499 visits) of its visitations were legitimate (Figure 5). The high number of legitimate visitations by *E. kamerunicus* was also supported by the high pollen loads on their bodies, hence indicating the high importance of this species as a pollinator in the study area (Table 3). Furthermore, the high abundance of this weevil at male oil palm inflorescences during the peak anthesis day (Swaray et al. 2021) coincide with the high abundance of viable pollen grains on the spikelets during this phase (Dhileepan 1992; Forero et al. 2012). Therefore, the weevils collected a great number of viable pollen grains on their bodies while visiting male inflorescences (Dhileepan 1992; Dzulhelmi et al. 2022). For this weevil, male individuals were found to carry approximately five times the amount of pollen grains than their female counterpart (Table 3). The total number of pollen grains carried by this weevil while visiting male inflorescences differed from the numbers estimated by Dhileepan (1992) and Dzulhelmi et al. (2022) likely due to the differences in the method applied to collect weevils from inflorescences, the total number of weevils observed and the method used to estimate the number of pollen grains.

Table 3. The visitor importance index (VII) value of the visitors of male oil palm inflorescences

Species	**Mean±SE of Visitation Rate (Visit/Hour)**	**Legitimate Visit (Mean±SE)**	**Total Pollen Load (Mean±SE)**	**VII Value**
			7205.45 ± 2 723.38	1.6×10^5
Elaeidobius kamerunicus	343.35 ± 241.85	656.19 ± 464.37	Male = 11121.43 ± 5261.25	2.5×10^5
			Female = 2901.852 ± 480.89	6.5×10^4
Dermaptera sp.	7.35 ± 2.10	2.94 ± 1.10	1500.00 ± 1100.00	3.24
Diacamma sp.	0.69 ± 0.20	0.06 ± 0.06	-	-
Anoplolepis gracilipes	4.00 ± 2.54	1.38 ± 1.21	-	-
Metamasius hemipterus	0.10 ± 0.06	0.06 ± 0.06	-	-
Pyroderces sp.	12.53 ± 7.05	19.44 ± 11.26	-	-
Thrips hawaiiensis	1.94 ± 1.19	2.69 ± 1.89	-	-
Eocanthecona sp.	3.60 ± 3.60	2.25 ± 2.25	-	-
Apis cerana	0.03 ± 0.03	0.06 ± 0.06	-	-
Buysmania oxymora	-	-	400.00 ± 0.00	-
Dolichogenidea metesae	-	-	17800.00 ± 0.00	-
Polyrhachis sp.	-	-	3000.00 ± 0.00	-
Hymenoptera sp.	-	-	200.00 ± 0.00	-
Diptera sp. 1	0.19 ± 0.19	0.25 ± 0.25	-	-
Diptera sp. 2	0.06 ± 0.06	0.13 ± 0.13	-	-
Diptera sp. 3	0.10 ± 0.1	0.1875 ± 0.19	-	-
Diptera sp. 4	0.16 ± 0.06	1.375 ± 1.21	-	-
Diptera sp. 5	0.25 ± 0.25	0.1875 ± 0.19	-	-
Diptera sp. 6	-	-	1479.07 ± 300.71	-
Hemiptera sp. 1	0.06 ± 0.06	0.00	-	-
Hemiptera sp. 2	0.06 ± 0.06	0.00	-	-

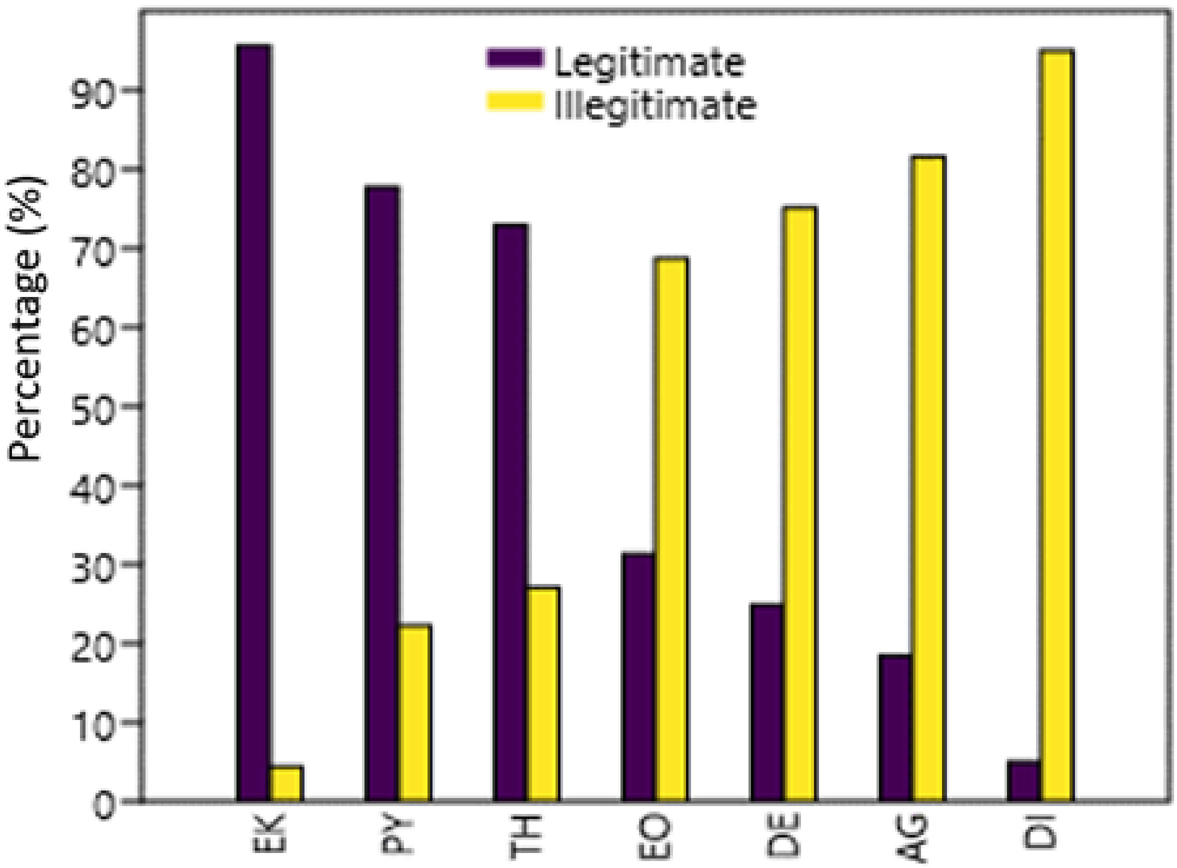

Figure 5. Visitation frequency (%) of the seven visitors to male oil palm inflorescences with a significant difference in the number of legitimate and illegitimate visits. EK = *Elaeidobius kamerunicus*, PY = *Pyroderces* sp., TH = *Thrips hawaiiensis*, EO = *Eocanthecona* sp., DE = Dermaptera sp., AG = *Anoplolepis gracilipes*, DI = *Diacamma* sp.

Sexual dimorphism is present in *E. kamerunicus*, with male individuals showing a relatively larger body size but shorter snouts than females (Abd Latip et al. 2019; Dzulhelmi et al. 2022; Muhammad Nasir et al. 2020). Moreover, compared with females, the males have more and wider hairs, and plural setae on their elytra that enables them to collect more pollen grains on their bodies (Dhileepan 1992; Dzulhelmi et al. 2022; Tambunan et al. 2020). Nevertheless, throughout the anthesis days, the abundance of female individuals at male inflorescences were always higher than those of their male counterparts (Swaray et al. 2021; Yue et al. 2015). Adaigbe et al. (2011) described the host specificity of females for oil palm male inflorescences as brood sites, thus explaining the high abundance of females at male inflorescences. However, present study study was unable to confirm this conjecture from video observations.

Pyroderces sp. had the second highest visitations, although with considerably fewer visitations by approximately 96% than *E. kamerunicus*. *Pyroderces* sp. is a native insect pollinator of oil palm trees cultivated in the Southeast Asian region other than *T. hawaiiensis* (Corley & Tinker 2016; Wahid & Kamarudin 1997). In the present study, *Pyroderces* sp. was observed to visit male inflorescences only during the night time because of its nature as a nocturnal species. The segregation in active time between *Pyroderces* sp. and the other two diurnal pollinators (*E. kamerunicus* and *T. hawaiiensis*) therefore likely a mechanism of their co-existence in oil palm plantations in Malaysia. The co-occurrence of the two diurnal pollinators was ascribed to their foraging behaviour (Anggraeni et al. 2013; Syed et al. 1982). For example, *T. hawaiiensis* avoids *E. kamerunicus* by actively foraging for oil palm pollen grains in the morning and late afternoon, whereas *E. kamerunicus* forages mainly during midday and consumes oil palm inflorescence parts only. Wahid and Kamaruddin (1997) further suggested a climatic factor in which *E. kamerunicus* thrive during the wet season and *T. hawaiiensis* during the dry season.

Compared with that on diurnal insect pollinators, little information is available on the role of nocturnal insects in the pollination success of oil palm trees. Nocturnal insects such as moths are efficient pollen vectors and hence contribute to key pollination services in natural and agricultural ecosystems (LeCroy et al. 2013; Walton et al. 2020). Amongst diurnal insect pollinators, hymenopteran bees are crucial pollinators of many agricultural crops worldwide (Ollerton et al. 2011). However, in the present study, *A. cerana,* the only bee species recorded, registered only one visit, although the visit was legitimate (Table 2). For oil palm inflorescences, visitation by hymenopteran bees is only casual and typically do not contribute to pollination (Sambathkumar & Ranjith 2011).

Despite showing a considerably lower number of visitations than *E. kamerunicus*, *Pyroderces* sp. and *T. hawaiiensis* nonetheless showed high legitimate visitations, with more than 70% of their total recorded visitations to male inflorescences (Table 2). However, data on the pollen carrying capacity of these two species were unavailable (Table 3). Hence, their importance as pollinators at the study site remains incompletely understood. Nevertheless, Wahid & Kamarudin (1997) observed functional complementarity by *T. hawaiiensis* in the pollination success of oil palm trees. During low pollination activities by *E. kamerunicus*, high fruit sets were reported to result from high pollination activities by this thrip. Montes Bazurto et al. (2018) reported a similar finding for oil palms in Columbia, in which the secondary pollinator, *Mystrops costaricensis* (sap beetle) was found to complement the low population size of the main pollinator (*E. kamerunicus*) in pollination success. Nevertheless, the present study recorded a comparatively very low visitation rate of *T. hawaiiensis*, likely because half of the data (eight days of the recordings) were collected during the wet season (January-February), during which the population size of this thrip was low in Malaysia (Wahid & Kamarudin 1997).

Dermaptera sp., *A. gracilipes*, *Eocanthecona* sp. (pentatomid bug) and *Diacamma* sp. (Asian Bullet Ant) showed a significantly higher number of illegitimate than legitimate visits (Table 2, Figure 5). These earwig, ant and pentatomid insect are generally predatory (Bos et al. 2008; Norman et al. 2017; Panabang et al. 2017). Thus, the earwigs and ants observed were likely preying on other insects foraging at male oil palm inflorescences. By heavily preying on the larvae of the coconut spike moth, *Tirathaba ruvifena*, the earwig species, *Chelisoches morio* (black earwig) exhibits a significant potential as natural predator (Zhong et al. 2016) of this important insect pest in oil palm plantations in Malaysia (Masijan et al. 2015). In the present study, earwig individuals were commonly seen at male inflorescences and probably reside on the inner part of the inflorescences. The captured earwig species, Dermaptera sp. showed numerous pollen grains on their bodies (Table 3), thus demonstrating high potential as a pollen vector in oil palm plantations. Lumentut et al. (2022) reported the potential role of the black earwig, *C. morio* as a pollinator of oil palm trees in Indonesia on the basis of the pollen grains on its body while visiting male and female oil palm inflorescences.

Meanwhile, *A. gracilipes* and *Diacamma* sp. are amongst the common ant species recorded in oil palm habitats in Indonesia (Johari et al. 2021). However, the pollen loads of these two ants and *Eocanthecona* sp. were not observed, although these insects made several legitimate visits to male inflorescences. Legitimate visits indicate their potential for collecting pollen grains on their bodies and their importance as oil palm pollen vectors. Given that oil palm trees produce male and female inflorescences separately, animal pollen vectors are essential for moving viable pollen grains from male to female inflorescences to initiate pollination (Syed 1979; Syed et al. 1982). In contrast to the earwig and the two ant species, *Eocanthecona* sp. is beneficial and is known to prey on nettle caterpillars (Norman et al. 2017), one of the most important pests in oil palm plantations (Corley & Tinker 2016).

Knowledge on the pollination potential of non-palynivore and non-nectarivore arthropods is rare but instructive (Willmer 2011). For example, the exclusion of jumping spiders (order Araneae, family Salticidae) from the inflorescences of the sensitive cassia (*Chamaecrista nictitans*) reduced the plant seed set by two-fold. However, this effect could be also contributed by the deterrent of seed predators on plants by the spiders (Ruhren & Handel 1999). Although known to hunt insects, these spiders were noted to have pollinator potential when observed to collect floral nectar occasionally while preying at cassia inflorescences.

Another example is the presence of a spider in various locations on the inflorescences of the small whorled pogonia (*Isotria medeoloides*), that later resulted in the development of seed capsules, indicating successful pollination (Horth 2019). Although the video observations acquired here did not detect any pollen transfer by this spider to other inflorescences, movement around the same flower might have enabled self-pollination in this rare terrestrial orchid. Accidental pollination is thus not only performed by predatory spiders, but also by struggling prey (van der Cingel 2001). In the present study, pollen loads were observed on several predatory insects, indicating their legitimate contacts with male oil palm inflorescences (Table 3). Nevertheless, no observations were conducted on pollen transferred to female inflorescences and fruit set to confirm pollination by these predatory insects, and no observations of the negative impacts on the insect pollinators were recorded in the present study. Thus, more studies are required to confirm the role of these predatory insects as pollinators of oil palm trees. Nonetheless, given that pollen load is an important proxy for measuring pollination potential, particularly for insects (e.g. Esposito et al. 2021; Gaffney et al. 2018; Murua 2020; Wolf & Moritz 2014), these findings add more knowledge on the role of predatory anthophilous insects in the pollination of oil palm inflorescences in Malaysia.

Many anthophilous insects are key pollinators of major plant crops in agricultural ecosystems worldwide (Klein et al. 2007; Ollerton et al. 2011). The high diversity of insect pollinators generally result in high pollination success in these ecosystems (Katumo et al. 2022). Insect pollinators are also useful for monitoring environmental health and controlling pest and disease in addition to providing of many cultural and aesthetical values. In recent years, however, many reports have indicated a global decline in these pollinator populations, hence threatening human wellbeing. The management of agricultural areas, such as oil palm plantations, is thus important for the conservation of this insect group. Perhaps, the Roundtable Sustainable Palm Oil (RSPO) and MSPO certification should be highly promoted to smallholders in Malaysia for the survival of important insect communities in the oil palm ecosystem.

Instead of the traditionally used abundance data, total insect visitations were used to determine the importance of insects as pollinators. Moreover, the potential pollen collection by the insects was noted by observing the point of contact made by the insects at the male inflorescences. Finally, pollen collection by the insects was confirmed by the examination of the pollen on the insects captured in a previous study conducted at the same study site. Anthophilous insects are found to act as pollen vectors of oil palm inflorescences, and therefore likely pollinators in oil palm plantations. The findings from this study enhance the current understanding of the interactions between anthophilous insects and oil palm inflorescences, which influence their performance as pollinators of oil palm trees.

CONCLUSION

This study has further confirmed the role of *E. kamerunicus* as the crucial pollinator the oil palm trees, particularly the male individuals that are able to collect more pollen grains on their bodies. Another important finding is that predatory insects such *A. gracilipes*, *Diacamma* sp., *Eocanthecona* sp. and Dermaptera sp., are likely pollen vectors of oil palm. Although data on pollen loads are available for only several predatory insects, these insects were observed to make occasional legitimate visits to male inflorescences hence confirmed that legitimate visits resulted in pollen collection by insect visitors. Given that pollen collection usually results in pollen transfer for the occurrence of pollination, this study emphasised the importance of anthophilous insect communities in oil palm plantations as potential pollinators of economically important oil palm trees in Malaysia. Biodiversity-friendly management is thus crucial for the survival of this insect community in oil palm plantations.

AUTHORS DECLARATIONS

Funding Statement
This research was made available through funding from the Ministry of Higher Education, Malaysia, under the Fundamental Research Grant Scheme (FRGS) vot number 59532 [FRGS/1/2018/WAB01/UMT/01/1]. This research was also partially funded by TDM Sdn. Bhd. through the University-Industry grant project vot number 53262 [UMT/RMIC/2-2/25/Jld. 4(37)].

Conflict of Interest
The authors declare that they have no conflict of interest.

Ethics Declarations
The authors declare that the field work was conducted with the permission of Terengganu Management and Development (TDM) Plantation Sdn. Bhd.

Data Availability Statement
The author confirms that the data supporting the findings are available within the article. Raw data available from the corresponding author upon reasonable request.

Authors Contributions
Mohamed Nor Zalipah (MNZ), Nur Fariza M.Shaipulah (NFMS), Norasmah Basari(NB), and Asraf Mohamad Idrus (AMI) conceived this research and designed experiments; MNZ and Shahrul Anuar Mohd Sah ()SAMS participated in the design and interpretation of the data; Siti Zulaikha 'Afifi (SZA), Nurul Atiqah Mohd Yasin (NAMY), Nur Solehah Othman (NSO), Hui Ting Tan (THT), Nurul Izzah Azuan (NIA), Muhamad Azrul Shaiful Lizam (MASL) and Faiq Zulfaqar ZairiFZZ performed experiments and analysis; SZA, MNZ and SAMS wrote the paper and participated in the revisions of it. All authors read and approved the final manuscript.

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