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POPULATION DENSITY OF *Elaeidobius kamerunicus* FAUST AND ABIOTIC FACTORS EFFECT WITHIN ANTHESISING INFLORESCENCES OF MALAYSIAN OIL PALM

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ABSTRACT

Elaeidobius kamerunicus is an important pollinator in Malaysian oil palm cultivation. After four decades of introduction, there are still reports of low fruit set for oil palm planted on mineral and peat soil areas in Malaysia. A comprehensive report on the population density of the weevil within the anthesising days with regard to Malaysia's climate is still lacking. Thus, this study aimed to elucidate the *E. kamerunicus* population density during anthesising days at both male and female inflorescence of oil palm by investigating the predominant soil affected with low fruit set, namely mineral and peat soil. The study was conducted from July 2022 to June 2023. At female inflorescence, the *E. kamerunicus* population was assessed by setting up a yellow sticky trap daily from 1st to 4th day of anthesis. On male inflorescence, the weevil population was assessed by counting the *E. kamerunicus* present on the spikelet from 1st to 5th day of anthesis. Correlation between abiotic factors and the *E. kamerunicus* population was analysed using statistical software. On the female inflorescence, anthesising day revealed a significant difference (*P<0.01*) in the weevil population density per inflorescence. Further analysis indicates no significant difference between the 1st and 2nd-day female anthesis in the *E. kamerunicus* population and the highest visitation on 1st day of anthesis. The abiotic factor did not influence the weevil population on peak anthesising days. The *E. kamerunicus* population density per spikelet and per inflorescence were significantly different (*P<0.01*) between anthesising days at male inflorescence. Further analysis between the 3rd-day anthesis and other days indicates significant differences, with the highest population congregation on the 3rd day. During peak population density on male inflorescence, the temperature depicted a significant, negative and weak relationship with the *E. kamerunicus* population. The female *E. kamerunicus* was observed highest at both inflorescences compared to the male *E. kamerunicus*. This study provides comprehensive evidence of higher population density of the weevil on a specific day of anthesis and can be used as a reference to monitor the *E. kamerunicus* pollination activity.

Keyword: Pollinating weevil, anthesising inflorescence, rainfall, relative humidity, temperature

ABSTRAK

Elaeidobius kamerunicus adalah agen pendebunga yang penting kepada penanaman sawit di Malaysia. Selepas empat dekad diperkenalkan, terdapat ladang sawit di tanah mineral dan tanah gambut di Malaysia dilaporkan mempunyai set buah yang rendah. Laporan komprehensif mengenai kepadatan populasi *E. kamerunicus* ketika antesis berdasarkan iklim Malaysia masih kurang. Justeru, kajian ini bertujuan untuk memahami kepadatan populasi *E. kamerunicus* semasa antesis pada bunga jantan dan betina sawit pada kawasan tanah yang utama terjejas dengan set buah rendah, iaitu tanah mineral dan gambut. Kajian telah dijalankan dari Julai 2022 hingga Jun 2023. Pada bunga betina, populasi *E. kamerunicus* dinilai dengan memasang perangkap berpelekat kuning setiap hari dari hari pertama hingga keempat antesis Pada bunga jantan, populasi *E. kamerunicus* dinilai dengan mengira bilangannya yang terdapat pada spikelet dari hari pertama hingga kelima antesis. Korelasi di antara faktor abiotik dan populasi *E. kamerunicus* telah dinilai menggunakan perisian statistik. Pada bunga betina, hari antesis menunjukkan perbezaan yang sangat signifikan ($P<0.01$) terhadap tahap populasi kumbang per bunga. Analisis lanjut menunjukkan tiada perbezaan yang signifikan antara bunga yang antesis pada hari pertama dan hari kedua terhadap populasi kumbang serta kunjungan tertinggi berlaku pada hari pertama antesis. Populasi kumbang pada hari puncak antesis tidak dipengaruhi oleh faktor abiotik. Populasi kumbang per spikelet dan bunga menunjukkan perbezaan yang sangat ketara ($P<0.01$) antara hari antesis pada bunga jantan. Kajian seterusnya antara hari ketiga antesis dan hari-hari lain menunjukkan perbezaan signifikan dengan populasi tertinggi dilihat pada hari ketiga. Ketika puncak kepadatan populasi pada bunga jantan suhu adalah signifikan, hubungan yang lemah dan negatif dengan populasi *E. kamerunicus*. *Elaeidobius kamerunicus* betina lebih banyak ditemui pada kedua-dua bunga berbanding *E. kamerunicus* jantan. Kajian ini memberi bukti menyeluruh tentang kepadatan populasi *E. kamerunicus* yang lebih tinggi pada hari antesis tertentu dan dapat menjadi rujukan untuk mamantau aktiviti pendebungaan oleh *E. kamerunicus*.

Katakunci: Kumbang pendebungaan, bunga yang antesis, hujan, kelembapan, suhu

INTRODUCTION

The oil palm, *Elaeis guineensis* is a monoecious palm with male and female inflorescence occurring separately in different parts of the palm (Kushairi et al. 2019). In 1917, Malaysia's first commercial oil palm planting was established in Tannamaran Estate (Keong 2017). Meanwhile, the active planting of oil palm in Malaysia started in the mid-60s (Kushairi et al. 2019). After a century of commercial planting, the planted area in Malaysia as of 2022 was at

5.67 million ha, a reduction of 0.07 million ha from the previous year (Parveez et al. 2023). In Malaysia, the majority of the land is occupied by mature palms at 90%, followed by immature palms (MPOB 2023). Palm oil-based products contribute to RM137.89 billion in export revenue in the country (Parveez et al. 2023). In 2020, palm oil products were the fourth largest export, accounting for 4.7% of Malaysian exports (Malaysia External Trade Development Corporation 2021).

In the early period of oil palm cultivation in Malaysia, a screening study in Cameroon was conducted to identify the possible pollinator of oil palm in its native region for importation (Syed 1980). Post studies documented several possible pollinators of oil palm with dominant species *Elaeidobius* spp. (Syed 1981), where importation of single species of *Elaeidobius kamerunicus* from Cameroon was conducted to be integrated into Malaysian oil palm (Kang & Karim 1982; Syed et al. 1982). Following the introduction, *E. kamerunicus* was subsequently distributed throughout Malaysian oil palm cultivation. An earlier study documented six *Elaeidobius* spp in oil palm (Syed 1980). Nevertheless, a recent taxonomy study documented eight variant species with an addition of new species, namely *E. pilimargo* and *E. piliventris,* which were previously grouped as *E. singularis* (Haran et al. 2020). Importation of *E. kamerunicus* to Malaysia is due to a higher pollen load, good searching ability, higher population in wet and dry climates (Syed 1981) and specific host to *Elaeis* genus (Kang & Karim 1982; Syed 1981).

Recent reports revealed areas affected with low fruit sets despite introducing *E. kamerunicus* about four decades ago. According to an MPOB survey from 2016 to 2017, more than 88,000 ha out of 580,891.76 ha of survey area were affected, predominantly on mineral and peat soil (Kamarudin et al. 2018). Allocation of the affected area was 58% peat soil and the rest mineral soil. This issue raised concerns about the effectiveness of the single species weevil in Malaysia (Mohamad et al 2023). A recent review identified two main factors affecting the weevil efficiency; intrinsic and extrinsic factors. Intrinsic factors include weevil genetics and population, whereas extrinsic factors include climatic factors, pests and diseases associated with the weevil, estragole emission, type of soil, plant physiology and planting materials (Mohamad et al. 2023).

The fruit set formation level has been reported as an indicator for elucidating the weevil population effect (Mohamad et al. 2021; Riley et al. 2022). Nevertheless, population density within anthesising days of inflorescence in Malaysia is still lacking. This study aims to elucidate the behaviour through population density of the weevil during anthesising days at both male and female inflorescence of oil palm by focusing on the predominant soil affected with low fruit set, namely mineral and peat soil. This study also highlights the population within Malaysia's climate, complementing the studies conducted in China (Yue et al. 2015) and Indonesia (Permana et al. 2021).

MATERIALS AND METHODS

Sampling Sites

Elaeidobius kamerunicus population density study was conducted at mineral soil located at Felda Chuping 02, Kangar, Perlis, Malaysia (GPS: 6.514796, 100.294518) and peat soil at Bukit Payong Estate, Pekan, Pahang, Malaysia (GPS: 2.972720, 103.378296). The sampling sites map presented in Figure 1. The estates were planted with oil palm *dura* x *pisifera* planting material. The palms were planted in 2016 for Felda Chuping 02 and 2015 for Bukit Payong Estate. According to a previous study, the estate was selected based on the height and age of the palm, i.e., below 4 m for palms less than 10 years old according to a previous study (Tan et al. 2014). Thus, they were easily accessible for daily monitoring and sampling of the inflorescences. The experiment and data collection started in July 2022 and ended in June 2023.

Population Density on Anthesising Day for Female Inflorescence of Oil Palm

The anthesising days of the female inflorescence oil palm were divided into four days. Starting the anthesising day for female inflorescence was based on the guide presented in previous studies (Forero et al. 2012; Mubarok et al. 2022). Day 1 anthesis (phenological stage PS607) is described to have cream-coloured tri-lobe tepal with 70% of flowers bloomed flower. Day 2 had 100% open flower, and subsequently, Days 3 and 4. The population density was observed and sampled on the female inflorescence using a yellow insect sticky trap obtained from Chemibond Enterprise Sdn. Bhd. The sizing of the sticky trap was 33 cm x 21.5 cm. Firstly, the yellow sticky trap was mounted on top of an iron mesh wire of a similar size. The sampling using a sticky trap has been reported in several studies (Auffray et al. 2017; Beaudoin-Ollivier et al. 2017; Yue et al. 2015). The iron mesh was then placed on the anthesising female inflorescence at 8 am. The iron mesh with the yellow sticky trap was removed at 5 pm. The weevil caught on the yellow sticky trap gel was transported to the laboratory for population counting of the male and female weevil per inflorescence. Afterwards, the yellow sticky trap was deposited on top of a transparent plastic bag to preserve the yellow sticky trap and allow an accessible view of the weevil caught. This procedure was repeated for all anthesising days. Two female inflorescences were sampled monthly, and the study period was conducted with a cumulative of 12 months.

Population Density on Anthesising Day for Male Inflorescence of Oil Palm

The anthesising day at male inflorescence of oil palm was divided into five days, where the anthesising stage followed the percentage of flower opening on the spikelets. The 1st day was set at 25% flower open on the spikelet, then increased to 50% on 2nd day and 100% on 3rd day. The 4th and 5th days followed afterwards with a reduction of flower opening. This classification follows the prescribed method by (Chiu et al. 1986; Yue et al. 2015) with a modification of sampling anthesising days to 5 days because none of the weevils was recorded on the 6th and 7th days during preliminary observation. The sampling of the population density of the weevil on male inflorescence was conducted between 8 to 10 am before the active period of the weevil on male inflorescence between 11 am to 12 pm (Permana et al. 2021; Yue et al. 2015). The male inflorescences were divided into three sections: top, middle and bottom. In each section, two spikelets were sampled and placed inside plastic bags before population determination was conducted in the laboratory. The sampling method was slightly modified by reducing the spikelet sampled compared to Chiu et al. (1986). At the laboratory, the male and female weevil was sorted to calculate the male, female and total population density of weevil per spikelet. Then, the population density per inflorescence was calculated using below formula:

$$\begin{aligned}&Population\ density\ E.kamerunicus\ per\ inflorescence\\&= number\ of\ weevil\ per\ spikelet\ x\ total\ spikelet\ per\ inflorescence\end{aligned}$$

This method was repeated for all anthesising days. Two male inflorescences were sampled monthly, and the study period was conducted with a cumulative of 12 months.

Data Analysis

The population density of the *E. kamerunicus* per spikelet and inflorescences was analysed using Kruskal-Wallies non-parametric analysis due to the normality test indicating a non-normal population distribution. Following that, significant differences observed between the anthesising days towards the population density were reanalysed using the Dwass, Steel, Critchlow-Fligner Method (Pairwise comparison) means comparison to determine the peak anthesising day for the weevil population. Daily rainfall data was obtained from designated plantation weather stations. The temperature and relative humidity were collected daily during sampling using Extech 45170 4-in-1 Environmental Meter. Correlation analysis was conducted between the weevil population and abiotic factors: rainfall, temperature and relative humidity. All the statistical analyses were conducted using SAS 9.4 software.

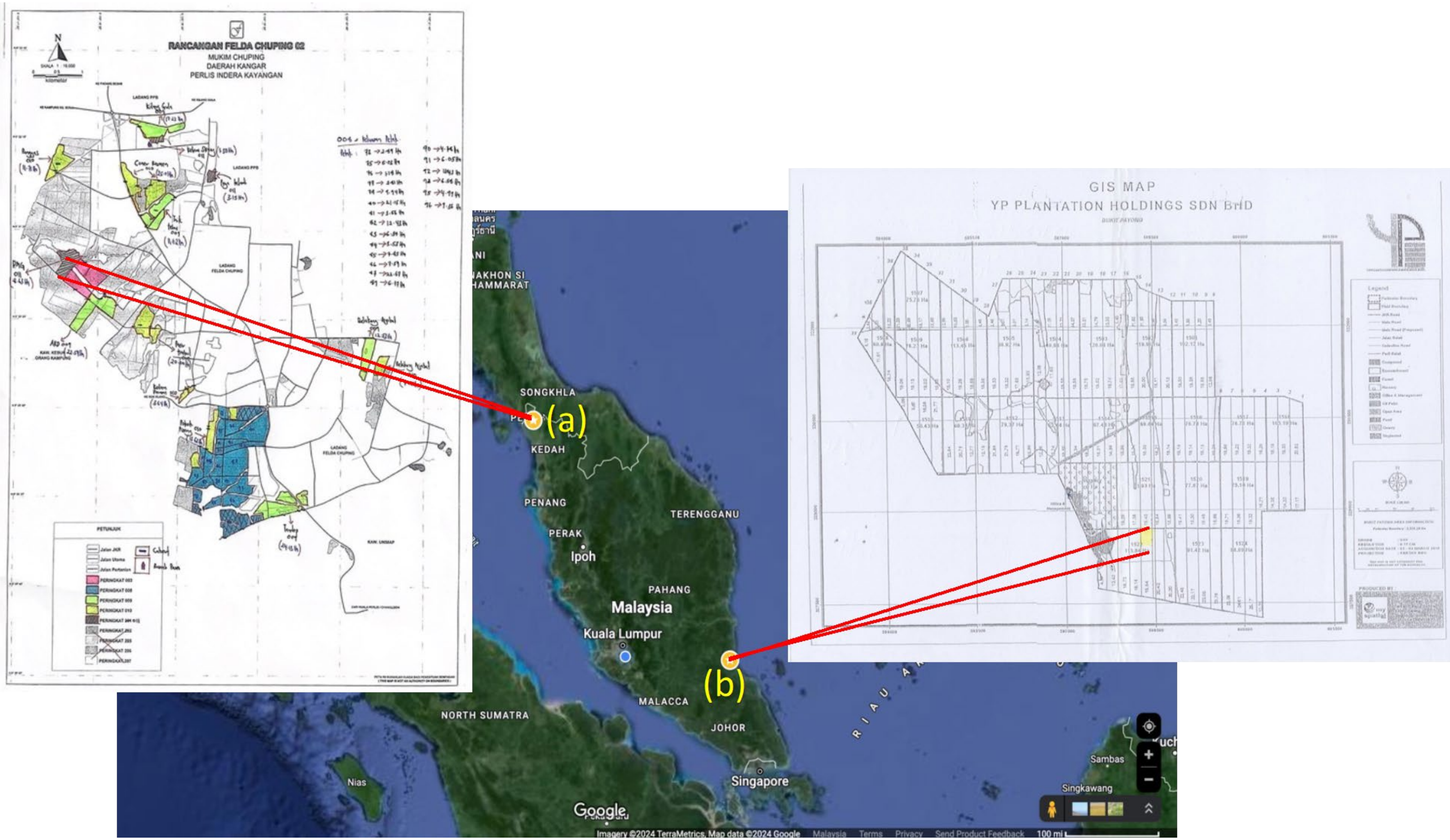

Figure 1. Map showing the sampling sites: (a) Felda Chuping 02, Kangar, Perlis (GPS: 6.514796, 100.294518) and (b) Bukit Payong Estate, Pekan, Pahang (GPS: 2.972720, 103.37829)

RESULT

Overall Population Density of *E. kamerunicus* on Anthesising Female Inflorescences

The overall result indicates the anthesising female inflorescence (AFIF) was significantly different in terms of the total population density of the *E. kamerunicus* per inflorescence (Chi-square=98.0681, *P<0.01*). Significant differences were also observed between the AFIF towards the overall female population density of *E. kamerunicus* per inflorescence (Chi-square=97.3742, *P<0.01*) and overall male population density of *E. kamerunicus* per inflorescence (Chi-square=96.3258, *P<0.01*).

Plotting of the mean weevil population indicates the highest total population density/inflorescence, female population density/inflorescence and male population density/inflorescence were observed on anthesising female inflorescence Day-1 at 502.06±172.23, 380.04±133.02 and 122.02±39.41 weevils per inflorescence as Figure 2. Despite the highest population being recorded on Day 1, a pairwise comparison of the weevil population indicates no significant difference between anthesising day (1 vs 2) for all the parameters: total population density/inflorescence, female population density/inflorescence and male population density/inflorescence (P>0.05). This result reflects that both days were at par with each other towards the weevil population on AFIF. The data are presented in Table 1.

The rest of the pairwise comparison revealed a significant difference between the anthesising day pair and the weevil population. Thus, the first and second days contribute the highest weevil population at female inflorescence and differ from other anthesising days. The female population was almost three times higher than the male population when comparing the sexes of the weevil population per inflorescence at AFIF. This implies a higher visitation by the female weevil during anthesising at female inflorescence.

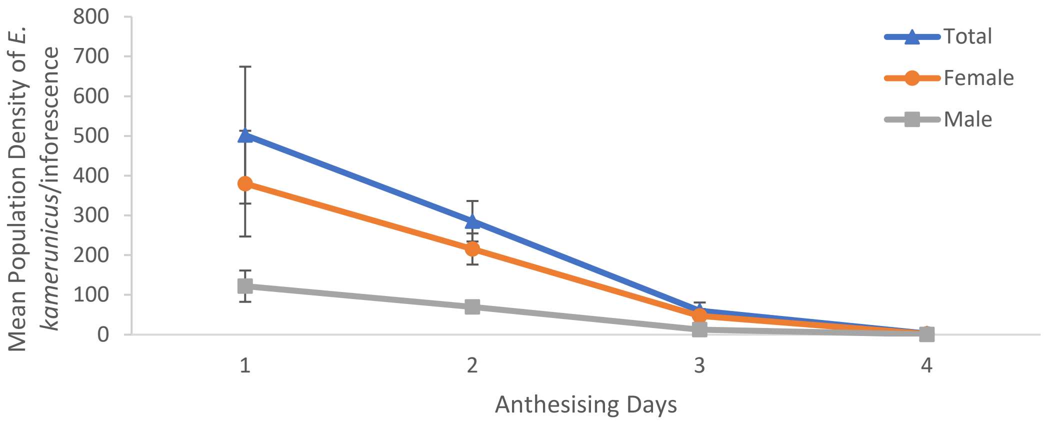

Figure 2. *Elaeidobius kamerunicus* population per inflorescence according to anthesising day of female inflorescence (AFIF)±SE

Table 1. Pairwise comparison between the anthesising day of female inflorescence (AFIF) towards the overall population density of *E. kamerunicus* per inflorescence

Day	***E. kamerunicus* population/inflorescence (P-value)**		
	Total	**Female**	**Male**
		Pr>DSCF	
1 vs. 2	0.425[NS]	0.4033 [NS]	0.295[NS]
1 vs. 3	<.0001**	<.0001**	<.0001**
1 vs. 4	<.0001**	<.0001**	<.0001**
2 vs. 3	<.0001**	<.0001**	<.0001**
2 vs. 4	<.0001**	<.0001**	<.0001**
3 vs. 4	0.0015**	0.0018**	0.002**

Note. **Highly significant at $P<0.01$ and [NS]Non-significant at $P>0.05$ using Dwass, Steel, Critchlow-Fligner (DSCF) pairwise comparison method

Overall Population Density *E. kamerunicus* on Anthesising Male Inflorescences

The overall population at anthesising male inflorescence (AMIF) depicted significant differences ($P<0.01$) between anthesising days towards the total population of *E. kamerunicus* per spikelet (Chi-square=318.5669, $P<0.01$) and per inflorescence (Chi-square=329.0807, $P<0.01$). In addition, the female population *E. kamerunicus* per spikelet (Chi-square= 306.5396, $P<0.01$) and per inflorescence (Chi-square= 315.2443, $P<0.01$) were significantly different on the anthesising day. Furthermore, the male population of *E. kamerunicus* per spikelet (Chi-square= 222.9906, $P<0.01$) and per inflorescence (Chi-square= 230.6192, $P<0.01$) were found to be significantly different on the anthesising day.

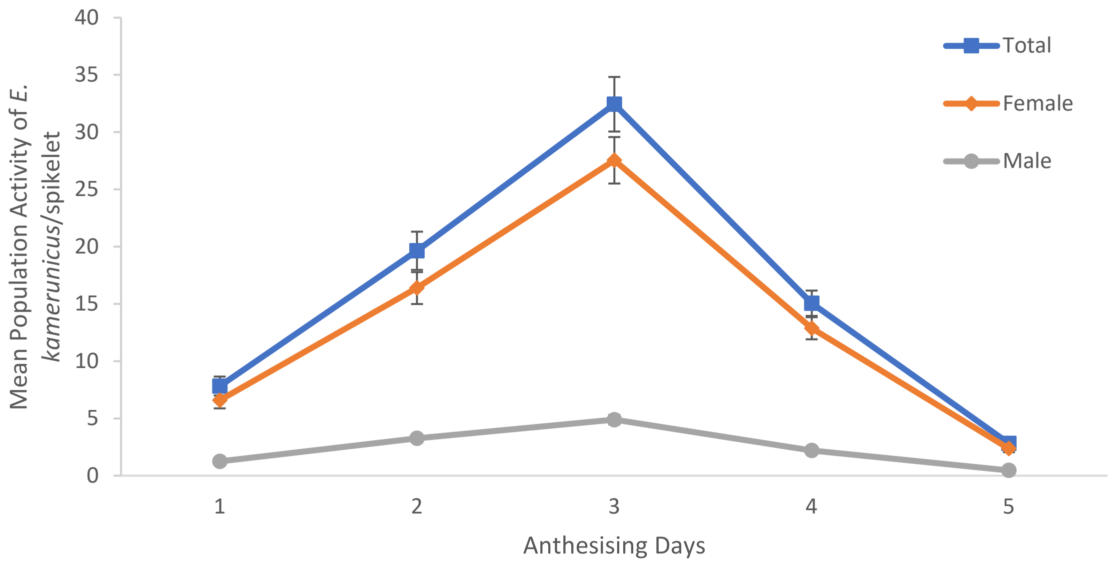

Figure 3. *Elaeidobius kamerunicus* population per spikelet according to anthesising day of male inflorescence (AMIF)±SE

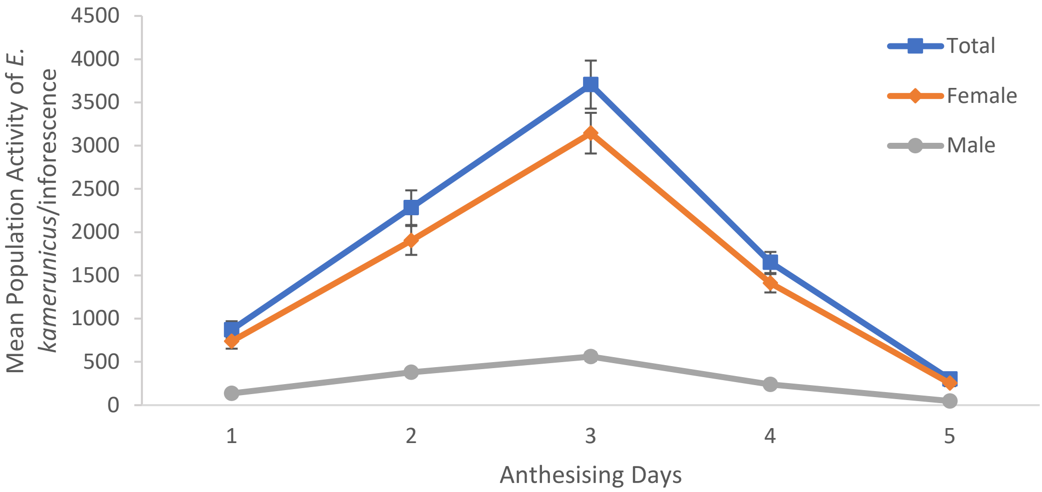

Figure 4. *Elaeidobius kamerunicus* population per inflorescence according to anthesising day of male inflorescence (AMIF)±SE

In terms of the overall weevil population per spikelet, the highest average population was recorded on anthesising male inflorescence day-3 with average population total population density/spikelet at 32.44±2.38, female population density/spikelet at 27.54±2.03 and male population density/spikelet at 4.89±0.41. Results are presented in Figure 3. Pairwise comparison between anthesising days (3 vs 1, 2, 4 and 5) at individual pairwise were significantly different (*P<0.01*) between the anthesising day towards the total, female and male population density/spikelet. Table 2 depicts that the population per spikelet on day 3 was highest compared to the other anthesising days at male inflorescence, and the values were significantly different.

For the overall weevil population per inflorescence, the average population was highest during the 3rd day anthesising male inflorescence with a mean total population density/inflorescence of 3706.07±277.54, female population density/inflorescence = 3144.50±234.99 and male population density/inflorescence = 561.57±48.96 (Figure 4). This was further supported by pairwise comparisons between individual anthesising day 3 vs 1, 2, 4 and 5, demonstrating significant differences (*P<0.01*) toward the weevil population per inflorescence, as shown in Table 2. This result indicates that the highest population was on 3rd day of anthesising male inflorescence.

The female weevil population per spikelet was more than five times greater than the male. The female weevil population per inflorescence was greater than five times the male weevil population. Therefore, females congregate at a greater value on male inflorescence during peak anthesising day.

Table 2. Pairwise comparison between the anthesising day of male inflorescence (AMIF) towards the overall population density of *E. kamerunicus* per spikelet and inflorescence

Day	***E. kamerunicus* Population/Spikelet**			***E. kamerunicus* Population/Inflorescence**		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**
	Pr>DSCF					
1 vs. 2	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**
1 vs. 3	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**
1 vs. 4	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**
1 vs. 5	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**
2 vs. 3	0.0045**	<.0001**	<.0001**	0.0075**	<.0001**	<.0001**
2 vs. 4	0.9998NS	0.9646NS	0.9532NS	0.9999NS	0.9682NS	0.9562NS
2 vs. 5	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**
3 vs. 4	0.0012**	<.0001**	<.0001**	0.0018**	<.0001**	<.0001**
3 vs. 5	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**
4 vs. 5	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**	<.0001**

Note. **Highly significant at *P<0.01* and NSNon-significant at *P>0.05* using Dwass, Steel, Critchlow-Fligner (DSCF) pairwise comparison method

Relationship Between Abiotic Factors and Total Population Density *E. kamerunicus* on Anthesising Female Inflorescences

Correlation analysis on the effect of abiotic day on the overall population density of the weevil was conducted through sorting of anthesising days. On the 2nd day of anthesis, only rainfall had a significant positive but weak relationship with the male population density of *E. kamerunicus* per inflorescence. Nevertheless, the peak population density during the 1st and 2nd days of anthesis reflected that the weevil population was unaffected by abiotic factors. On the contrary, the weevil population was affected by temperature with a negative and weak correlation during the 3rd day anthesis. Finally, on the last day of anthesis (Day 4), there was a significant positive but weak correlation between the weevil population density per inflorescence and rainfall. Result presented in Table 3.

Relationship Between Abiotic Factors and Total Population Density *E. kamerunicus* on Anthesising Male Inflorescences

On the 1st day of anthesis, the temperature and relative humidity revealed a weak significant relationship with the weevil population per inflorescence and per spikelet. The temperature had a negative relationship, whereas the relative humidity demonstrated a positive relationship. During the 2nd day of anthesis, the male population per spikelet and per inflorescence and the total population per spikelet had a significant positive and weak correlation with rainfall. The peak population density of the weevil on male inflorescence was recorded on the 3rd day of anthesis. The temperature reflected a negative and weak relationship between the female and total weevil population. The result was similar on the 4th day of anthesis, where the temperature depicted a significant relationship. The effects of rainfall were absent on the 3rd to 5th days of anthesis as the abiotic factor was not recorded on the meteorology weather station. Result presented in Table 4.

Table 3. Correlation between temperature, relative humidity, rainfall and the total population density of *E. kamerunicus* per inflorescence on the anthesising day of female inflorescence (AFIF),

AFIF	Day 1			Day 2			Day 3			Day 4		
	Temp	RH	Rainfall	Temp	RH	Rainfall	Temp	RH	Rainfall	Temp	RH	Rainfall
MPIF	-0.02092	-0.06012	-0.07392	-0.13219	0.01637	0.34819	-0.28663	0.17867	-0.1753	0.01296	-0.04064	0.43698
	0.8878^{NS}	0.6848^{NS}	0.6176^{NS}	0.3705^{NS}	0.912^{NS}	0.0153*	0.0483*	0.2243^{NS}	0.2334^{NS}	0.9303^{NS}	0.7839^{NS}	0.0019*
FPIF	-0.01897	-0.05501	-0.06403	-0.18352	0.09751	0.19946	-0.32924	0.2205	-0.16373	-0.02054	-0.04124	0.44184
	0.8982^{NS}	0.7104^{NS}	0.6655^{NS}	0.2118^{NS}	0.5097^{NS}	0.1741^{NS}	0.0223*	0.1321 ^{NS}	0.2661^{NS}	0.8898 ^{NS}	0.7808^{NS}	0.0017*
TPIF	-0.01944	-0.05624	-0.06637	-0.17445	0.07916	0.24098	-0.32213	0.21327	-0.16629	-0.01091	-0.04127	0.44268
	0.8957^{NS}	0.7042^{NS}	0.654^{NS}	0.2357^{NS}	0.5928^{NS}	0.0989^{NS}	0.0256*	0.1456 ^{NS}	0.2586^{NS}	0.9413^{NS}	0.7806^{NS}	0.0016*

Note. * Significant at $P<0.05$ and ^{NS}Non-significant at $P>0.05$. Total population density of *E. kamerunicus* per inflorescence (TPIF), female population density of *E. kamerunicus* per inflorescence (FPIF) and male population density of *E. kamerunicus* per inflorescence (MPIF)

Table 4. Correlation between temperature, relative humidity, rainfall and the total population density of *E. kamerunicus* per spikelet and inflorescence on the anthesising day of male inflorescence (AMIF).

AMIF	Day 1			Day 2			Day 3			Day 4			Day 5		
	Temp	RH	Rainfall	Temp	RH	Rainfall	Temp	RH	Rainfall	Temp	RH	Rainfall	Temp	RH	Rainfall
MPS	-0.15827	0.15705	-0.07083	-0.04702	0.0617	0.18633	-0.10475	-0.00047	.	0.07795	0.14562	.	-0.0225	0.05616	.
	0.0084*	0.009*	0.2409^{NS}	0.436^{NS}	0.3071^{NS}	0.0019*	0.0824^{NS}	0.9937^{NS}	.	0.1871^{NS}	0.0134*	.	0.7038^{NS}	0.3423^{NS}	.
FPS	-0.16323	0.18009	-0.07602	-0.07039	0.05201	0.11094	-0.16914	0.00913	.	0.18152	0.11383	.	-0.00643	0.02293	.
	0.0066*	0.0027*	0.208^{NS}	0.2438^{NS}	0.3894^{NS}	0.0657^{NS}	0.0048*	0.88^{NS}	.	0.002*	0.0536^{NS}	.	0.9135^{NS}	0.6984^{NS}	.
TPS	-0.16544	0.17965	-0.07657	-0.06724	0.05451	0.12606	-0.16184	0.00769	.	0.17047	0.12179	.	-0.0095	0.02971	.
	0.0059*	0.0027*	0.2047^{NS}	0.2656^{NS}	0.367^{NS}	0.0363*	0.0071*	0.8988^{NS}	.	0.0037*	0.0389*	.	0.8724^{NS}	0.6156^{NS}	.
MPIF	-0.19296	0.1807	-0.07345	-0.00493	0.03687	0.15872	-0.09464	0.0002	.	0.05858	0.12077	.	-0.01955	0.05514	.
	0.0013*	0.0026*	0.2239^{NS}	0.9351^{NS}	0.5419^{NS}	0.0083*	0.1167^{NS}	0.9974^{NS}	.	0.3219^{NS}	0.0406*	.	0.7411^{NS}	0.3512^{NS}	.
FPIF	-0.18196	0.1914	-0.0778	-0.02995	0.02535	0.09051	-0.16505	0.01354	.	0.14656	0.10151	.	-0.00597	0.02622	.
	0.0024*	0.0014*	0.1976^{NS}	0.6203^{NS}	0.675^{NS}	0.1336^{NS}	0.006*	0.8228^{NS}	.	0.0128*	0.0855^{NS}	.	0.9196^{NS}	0.6577^{NS}	.
TPIF	-0.18657	0.19272	-0.07833	-0.02589	0.02777	0.10399	-0.15644	0.0115	.	0.13681	0.10701	.	-0.00855	0.03227	.
	0.0019*	0.0013*	0.1945^{NS}	0.6685^{NS}	0.646^{NS}	0.0846^{NS}	0.0092*	0.8492^{NS}	.	0.0202*	0.0698^{NS}	.	0.8852^{NS}	0.5855^{NS}	.

Note. * Significant at $P<0.05$ and ^{NS}Non-significant at $P>0.05$. Total population density of *E. kamerunicus* per spikelet (TPS), female population density of *E. kamerunicus* per spikelet (FPS), male population density of *E. kamerunicus* per spikelet (MPS), total population density of *E. kamerunicus* per inflorescence (TPIF), female population density of *E. kamerunicus* per inflorescence (FPIF) and male population density of *E. kamerunicus* per inflorescence (MPIF)

DISCUSSION

Anthesising female inflorescence attracts the visitation of *Elaeidobius* spp. for pollination to occur. This event occurs through the odour released by the female inflorescence during anthesis starting at phenological stage PS607 (Forero et al. 2012; Mubarok et al. 2022) that attract the weevil for pollination. Nonetheless, female inflorescence does not provide food sources as male inflorescence; thus, the visitation occurs in short periods (Syed 1981). Reported study shown, shorter visitation period by the weevil on female inflorescence compare to male inflorescence (Afrian et al. 2020). The odour released by the inflorescence of oil palm was identified as estragole, a volatile organic compound (VOC) (Lajis et al. 1985). Despite the short visitation period by the weevil on female inflorescence, it contributes significantly towards producing of fresh fruit bunches (FFB).

Our study recorded the peak *E. kamerunicus* population density on anthesising female inflorescence on the 1st day of anthesis with the highest visitation per inflorescence. Nevertheless, the finding contradicts previous studies reported in Indonesia (Permana et al. 2021) and China (Yue et al. 2015), where the peak population density was recorded on the 2nd day of anthesis. In an earlier study conducted in Malaysia, a more significant amount of weevil was trapped on the 1st day of anthesis (Chiu et al. 1986). The characteristic of the 1st day of anthesising female inflorescence was about 7/10 of overall tri-lobe whitish colour tepal open (Chiu et al. 1986; Forero et al. 2012; Mubarok et al. 2022) and the presence of aniseed smell (Chiu et al. 1986).

Despite the varying results in the present study, statistical analysis revealed that no significant difference was recorded between 1st and 2nd day anthesising female inflorescence towards the weevil population per inflorescence. This indicates that both days contribute to high visitation by *E. kamerunicus* on female inflorescence. Several studies on the population density of *E. kamerunicus* at anthesising female inflorescence recorded significantly higher female weevil populations than male weevil populations (Permana et al. 2021; Yue et al. 2015). This report is similar to our finding regarding the female weevil population, which was two to three times greater than the male weevil population.

The population density of *E. kamerunicus* on anthesising female inflorescence was recorded during a six-day period in Indonesia (Permana et al. 2021) and China (Yue et al. 2015). Both studies reported no visitation by the weevil on the 6th anthesising day (Yue et al. 2015), and female inflorescence required 4 to 5 days to complete the anthesising period (Permana et al. 2021). The study in Malaysia reported no visitation by *E. kamerunicus* on 3rd day because it became post-anthesis with the characteristic of reddish colour tepal with reduced aniseed smell (Chiu et al. 1986). This study documented the four-day anthesising period as none or low visitation by the weevil on the 4th anthesising day. The characteristic of the 4th day observed in our study was a reddish purple-coloured tepal.

Male inflorescence of oil palm supports the development of *E. kamerunicus* by providing breeding locality and food sources (Syed 1981; Zulkefli et al. 2020). The male inflorescence is essential in the pollinator ecosystem. The weevil population was affected by the male inflorescence (Zulkefli et al. 2020), where the number of AMIF had a significant correlation with the weevil population per ha (Dhileepan 1994; Nurul Fatihah et al. 2018, 2019). In a review of factors affecting the efficiency of *E. kamerunicus,* the weevil population was identified as one of the sub-factors (Mohamad et al. 2023).

Several studies on population density at anthesising male inflorescence reported the peak population reported on the 3rd day of anthesis based on a study in Cameroon (Syed 1981), Indonesia (Permana et al. 2021) and China (Yue et al. 2015). Our studies also recorded similar findings where the population peaked on 3rd anthesising male inflorescence. The phenology of the anthesising male inflorescence is based on the flower opening, pollen and anise smell (Forero et al. 2012; Mubarok et al. 2022). The 3rd-day anthesis had the characteristic of 100% flower open and yellowish pollen covering all the spikelets, similar to the report by (Yue et al. 2015).

Throughout the studies on the anthesising male inflorescence, the female weevil population has been reported to have a greater population than the male weevil (Permana et al. 2021; Yue et al. 2015). Permana et al. (2021) recorded a highly significant difference between the female and male weevil populations. Proving the higher congregation of the female weevil on male inflorescence. Our report recorded a similar finding with a greater female weevil population by five times compared to a male weevil population, whether per spikelet or inflorescence. The early studies of *Elaeidobius* in Cameroon documented that the highest weevil during 3rd day of anthesis male inflorescence was *E. kamerunicus* (Syed 1981) as one of the factors contributing to the selection for importation and introduction to the Malaysia oil palm cultivated area (Syed 1979).

A population density study on anthesising male inflorescence was conducted through six-day observation in Indonesia and China (Permana et al. 2021; Yue et al. 2015). The population showed a reduction after 3rd day of anthesis until none was recorded on the 6th and 7th day (Permana et al. 2021; Yue et al. 2015). In our study, the reduction occurred in a similar trend with no weevil recorded on the 5th and 6th-day anthesis. On the 5th day of anthesis, the male inflorescence was observed with no pollen on at the spikelet, and the spikelet had turned dull brown, indicating post-anthesis.

Climate factor was listed as one of the factors affecting the efficiency of *E. kamerunicus* (Mohamad et al. 2023). Despite that, rainfall was stated as having minimal impact on the weevil population, and rainfall contributed to the impaired function of pollen transportation by the weevil (Mohamad et al. 2023). Several studies conducted between the weevil and the rainfall indicate no significant correlation, for instance in Columbia (Montes Bazurto et al. 2018) and India (Saravanan et al. 2023). Nevertheless, a weak positive correlation was recorded in Malaysia by Nurul Fatihah et al. (2018; 2019). This highlights the variation effect of rainfall on the weevil population and activity.

Another study documented the abiotic temperature and relative humidity factor on *E. kamerunicus* abundance. In a study conducted in Indonesia, Permana et al. (2021) found that temperature and relative humidity were significant, and they depicted a moderate and positive correlation with the abundance of *E. kamerunicus* on male and female inflorescence except for male inflorescence where humidity was negatively correlated. The study reported relative humidity (70 to 75%) and temperature (31 to 32°C) correlated with a higher weevil population (Permana et al. 2021). Moreover, higher temperatures also supported the foraging activity of the weevil. The results might differ; thus, further studies are required, especially in modelling the weevil behaviour.

CONCLUSION

The anthesising female inflorescence showed peak visitation during the 1^{st} day of anthesis and was no different from the 2^{nd} day of anthesis. This highlights that *E. kamerunicus* was attracted to the female inflorescence during the earlier anthesising period. Besides that, on anthesising male inflorescence, the weevil congregated the highest on 3^{rd} day of anthesis, where it was the peak blooming of the inflorescence. The female weevil was the highest population at both inflorescences of oil palm. The abiotic factor result varied according to day and was less attributed due to low correlation value. This study provides a report on the population density of the weevil with an emphasis on Malaysian oil palm cultivated area.

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The authors declare that they have no conflict of interest.

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No ethical issue is required for this research

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Authors' Contributions
Muhamad Haziq Hadif Zulkefli (MHHZ), Syari Jamian (SJ), Mohamed Mazmira Mohd Masri (MMMM), Ramle Moslim (RM) and Saharul Abillah Mohamad (SAM) conceptualized this research and designed experiments; MHHZ, SJ, Sumaiyah Abdullah (SA), MMMM and SAM participated in the design and interpretation of the data; MHHZ wrote the paper and SJ, Nur Azura Adam (NAA), SB, MMMM, RM and SAM participated in the revisions of it. All authors read and approved the manuscript.

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