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EFFECT OF SPIKELET POSITION AND SOIL TYPE ON THE POPULATION DENSITY OF *Elaeidobius kamerunicus* IN ANTHESISING OIL PALM MALE INFLORESCENCE

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ABSTRACT

In Malaysia, poor oil palm fruit setting on both peat and mineral soils continues to be reported, decades after the introduction of *Elaeidobius kamerunicus*. The population density of *E. kamerunicus* depends on the presence of anthesising male inflorescence. It was also previously suggested that the spikelet position on anthesising inflorescence can influence the weevil population. Therefore, this study aimed to analyse *E. kamerunicus* population density in relation to spikelet position across mineral and peat soil areas during the anthesising period of the male inflorescence. Sampling was conducted from July 2022 to June 2023. During the male inflorescence anthesis, weevils found on the spikelets were sampled and recorded. Sampling occurred daily from the 1st to the 5th day of anthesis. Simultaneously, additional data, including spikelet length, temperature, relative humidity, and rainfall, were also collected. Results revealed a significant difference in weevil population per spikelet based on spikelet position: on the 1st day of anthesis in mineral soil and on the 3rd day of anthesis in peat soil. The bottom spikelets consistently exhibited the highest weevil congregation, differ significantly from the population found on the top spikelets. Spikelet length also varied significantly with soil type and spikelet position. Mineral soil recorded the longest spikelets, significantly longer than those in peat soil. Conversely, the top spikelets were the shortest, significantly different from the middle and bottom spikelets. Correlation analysis between abiotic factors (relative humidity and temperature) and spikelet length against weevil population density per spikelet showed significant, albeit varied, correlations with the weevil population. These variations were observed across different anthesis days, spikelet positions, and soil types. This study highlights the influence of spikelet position on weevil population density per spikelet, providing valuable insights applicable to future weevil population censuses.

Keyword: Pollinating weevil population; position of spikelet; type of soil; anthesising male inflorescence

ABSTRAK

Di Malaysia, hasil buah yang rendah pada tanah gambut dan mineral terus dilaporkan, berdekad lamanya selepas pengenalan *Elaeidobius kamerunicus*. Kepadatan populasi *E. kamerunicus* bergantung kepada bunga jantan sawit yang sedang antesis. Pendapat menyatakan bahawa kedudukan spikelet pada bunga antesis boleh mempengaruhi populasi kumbang. Oleh itu, kajian ini bertujuan untuk menganalisis kepadatan populasi *E. kamerunicus* pada kedudukan spikelet yang berlainan di kawasan tanah mineral dan gambut semasa hari antesis bunga jantan. Persampelan telah dijalankan dari Julai 2022 hingga Jun 2023. Semasa antesis bunga jantan, kumbang yang berkumpul pada spikelet telah disampel dan direkodkan. Persampelan telah dijalankan setiap hari dari hari pertama hingga hari kelima antesis. Serentak itu, data tambahan, termasuk panjang spikelet, suhu, kelembapan relatif dan taburan hujan turut dikumpulkan. Hasil kajian menunjukkan terdapat perbezaan signifikan dalam populasi kumbang setiap spikelet berdasarkan kedudukan spikelet: pada hari pertama antesis di tanah mineral dan pada hari ketiga antesis di tanah gambut. Spikelet bahagian bawah secara konsisten menunjukkan tumpuan kumbang tertinggi, berbeza secara signifikan daripada populasi yang ditemui pada spikelet bahagian atas. Panjang spikelet juga menunjukkan perbezaan signifikan mengikut jenis tanah dan kedudukan spikelet. Tanah mineral merekodkan spikelet yang paling panjang, jauh lebih panjang berbanding spikelet di tanah gambut. Sebaliknya, spikelet bahagian atas adalah yang paling pendek, berbeza secara signifikan daripada spikelet bahagian tengah dan bawah. Analisis korelasi antara faktor abiotik (kelembapan relatif dan suhu) dan panjang spikelet berbanding kepadatan populasi kumbang setiap spikelet menunjukkan korelasi yang signifikan, walaupun bervariasi, dengan populasi kumbang. Variasi ini direkodkan merentasi hari-hari antesis, kedudukan spikelet dan jenis tanah yang berbeza. Kajian ini menunjukkan pengaruh kedudukan spikelet terhadap kepadatan populasi kumbang bagi setiap spikelet, serta memberikan maklumat penting yang boleh diaplikasikan untuk bancian populasi kumbang di masa hadapan.

Kata Kunci: Populasi kumbang pendebungaan; kedudukan spikelet; jenis tanah; bunga jantan yang antesis

INTRODUCTION

Oil palm (*Elaeis guineensis*), an African variety, is widely cultivated as a commodity on Malaysian plantations. It is a monoecious palm, bearing separate male and female inflorescences in distinct positions on the same plant (Forero et al. 2012; Kushairi et al. 2019; Mubarok et al. 2022) which are crucial for the survival and function of the pollinating weevil, *Elaeidobius kamerunicus*. Specifically, anthesising male inflorescences provide vital breeding and feeding grounds for this pollinator (Syed 1979). The entire pollinator ecosystem relies on these male inflorescences, which directly influence the weevil population (Zulkefli et al. 2020). Indeed, a significant correlation has been established between the number of anthesising male inflorescences and the number of weevils per hectare (Dhileepan 1994; Nurul Fatihah et al. 2018; Nurul Fatihah et al. 2019).

Phenological studies of oil palm, from vegetative growth to bunch production, indicate that male inflorescence anthesis is characterised by flowers opening from the base (at 70% on each spikelet), the presence of pollen in the anther, and the release of an anise-like odour (Forero et al. 2012; Mubarok et al. 2022). This stage is formally designated as PS607. The distinctive anise-like scent originates from the release of the volatile organic compound (VOC) estragole or 1-methoxy-4-(2-propenyl) benzene (Lajis et al. 1985). Globally, studies on anthesising male inflorescences consistently report a peak in weevil population density on the third day of anthesis in China (Yue et al. 2015), Indonesia (Permana et al. 2021), India (Saravanan et al. 2024) and Malaysia (Swaray et al. 2021; Zulkefli et al. 2024). This observation aligns with the original findings from Cameroon (Syed 1981a), where the third day of anthesis is described by fully open flowers, pollen presence, and an aniseed odour. During these anthesising stages, weevil congregations occur on male inflorescences, while weevil visitations are noted on female inflorescences. Understanding these behaviours is crucial for monitoring weevil populations and elucidating their respective roles during the anthesis period.

Pollinators are crucial for achieving desired fruit bunch production. *E. kamerunicus* was introduced into Malaysian oil palm cultivation in the early 1980s from its country of origin, Cameroon. This introduction followed extensive comparisons between oil palm cultivation practices in Cameroon and Malaysia (Syed 1979; Syed 1981a; Syed 1981b; Tay 1981). The culmination of these observations led to the importation and release of *E. kamerunicus*, a single pollinator species selected for its ability to acclimatise to Malaysian oil palm conditions (Syed et al. 1982). Subsequently, a neighbouring country also adopted this pollinator from the Malaysian population (Hutauruk et al. 1985).

Despite the established relationship between weevil pollinator populations and fruit set, low fruit set remains a persistent issue in some regions of Malaysia and Indonesia. Recent reports have raised concerns about the effectiveness of relying solely on *E. kamerunicus* as a single pollinator species in Malaysia (Kamarudin et al. 2018; Mohamad et al. 2023). This concern stems directly from widespread reports of low fruit set in affected areas. In Malaysia, low fruit set has been reported on both peat and mineral soils, impacting approximately 88,381 hectares out of a surveyed area of 580,891.76 hectares (Kamarudin et al. 2018).

The pollinating effectiveness of *E. kamerunicus* is influenced by both intrinsic factors (e.g., genetics and population dynamics of *E. kamerunicus*) and extrinsic factors (e.g., planting material, soil type, plant physiology, volatile organic compounds (VOCs), pests, disease, and climate) (Mohamad et al. 2023). Several studies have reported an association between the anthesising stage of inflorescence and weevil population density, for instance, in China (Yue et al. 2015), Indonesia (Permana et al. 2021) and India (Saravanan et al. 2024) and while these studies typically examine weevil population density on both male and female inflorescences, research specifically on male inflorescence during anthesis in Malaysia remains limited, with one notable report by Swaray et al. (2021). Their work focused on *DxP* hybrid varieties in deep peat areas and the weevil population density on male inflorescences. All these studies build upon and complement the initial population study and review involving the oil palm pollinator in Cameroon (Syed 1981a).

Kamarudin et al. (2018) identified peat and mineral soils in Malaysia as areas experiencing the lowest fruit set. Building on this, the current study specifically investigated weevil population density during the anthesising days of male inflorescences, with respect to spikelet position, in these low fruit set-associated soil types. While various studies have explored soils linked to low fruit set (Mohamad et al. 2021a; Mohamad et al. 2021b; Swaray et al. 2021), a comprehensive global perspective remains elusive. A statistical understanding of weevil population density throughout each anthesising day on male inflorescences is crucial for monitoring the pollinating weevil population. The objectives of this study were to analyse the population density of *E. kamerunicus* on male inflorescences during anthesis in relation to spikelet position and to correlate abiotic factors with *E. kamerunicus* population density during anthesis across different spikelet position and soil types.

MATERIALS AND METHODS

Study and Sampling Sites

The study utilised established oil palm plantations on peat soil at Bukit Payong Estate, Pekan, Pahang (GPS: 2.972720, 103.378296) and mineral soil at Felda Chuping 02, Kangar, Perlis (GPS: 6.514796, 100.294518). Both sites cultivated the *Dura x Pisifera* planting material. The locations were selected due to the age of the palms, which were under ten years old-planted in 2015 at Bukit Payong Estate and in 2016 at Felda Chuping 02. This age criterion was important, as previous studies have documented palms less than 10 years old typically have a height of under 4 m (Tan et al. 2014), thereby facilitating daily observation and sampling of inflorescences. Data collection commenced in July 2022 and concluded in June 2023. Sampling was conducted across a 4-hectare area at each site. Planting distances were 9 m x 9 m at Felda Chuping 02 and 8.83 m x 8.83 m at Bukit Payong Estate, resulting in a consistent planting density of 148 palms per hectare at both locations.

Sampling of *Elaeidobius kamerunicus* Population Density During Male Inflorescence Anthesis

The phenological stages for anthesising male oil palm inflorescences adhered to the descriptions by Forero et al. (2012) and Mubarok et al. (2022). Indications of anthesis included opening from the base, the presence of anthers with pollen, and the release of an anise-like smell, chemically identified as estragole. Before commencing the sampling of anthesis male inflorescences, a census was performed on all 592 palms within the 4-hectare sampling area. This preliminary step was crucial for identifying inflorescences corresponding to the first day of anthesis. All subsequent sampling was conducted on the same anthesising male inflorescences from Day 1 to Day 5. Each month, two different palms were utilised for sampling.

The anthesising period of male inflorescence was categorised into five distinct days. This grouping followed the methodology outlined by Chiu et al. (1986) and Yue et al. (2015), but excluded the sixth and seventh anthesising days, as preliminary studies confirmed the absence of weevils on the spikelets during these periods. Day 1 was characterised by 25% flower opening from the bottom section of the spikelet, Day 2 by 50% flower opening, and Day 3 by 100% flower opening. Days 4 and 5 were marked by a progressive reduction of pollen on the spikelet surface.

Sampling for the population density of *E. kamerunicus* per spikelet involved collecting spikelets inhabited by weevils. Each male inflorescence was divided into three sections: top, middle, and bottom. Sectioning of the inflorescence was presented in Figure 1. Two spikelets were sampled daily from each section. The sampling strategy, adapted from Chiu et al. (1986), was modified by reducing the number of spikelets sampled per section from three to two. This reduction was implemented to limit the total number of sampled spikelets to 30 per inflorescence. The total number of spikelets per inflorescence naturally increases with the age of the palm, growing from approximately 60 spikelets in 3-year-old palms to 150 in 10-year-old palms (Prabowo et al. 2021). Each sampled spikelet was immediately placed into a plastic bag. In the laboratory, the weevil population per spikelet was determined by sexing individual weevils, and the length of each spikelet was also recorded. Spikelet sampling was conducted daily between 8 a.m. and 10 a.m., prior to the weevils' active period to ensure sampling of the weevil did not cause agitated to the weevil congregation, consistent with methods used by Nurul Fatihah et al. (2018). The study spanned one year, with data collected monthly. Each month, two male inflorescences were sampled per soil type within the designated sampling areas. This approach follows the protocol established by Riley et al. (2022), who similarly sampled two inflorescences.

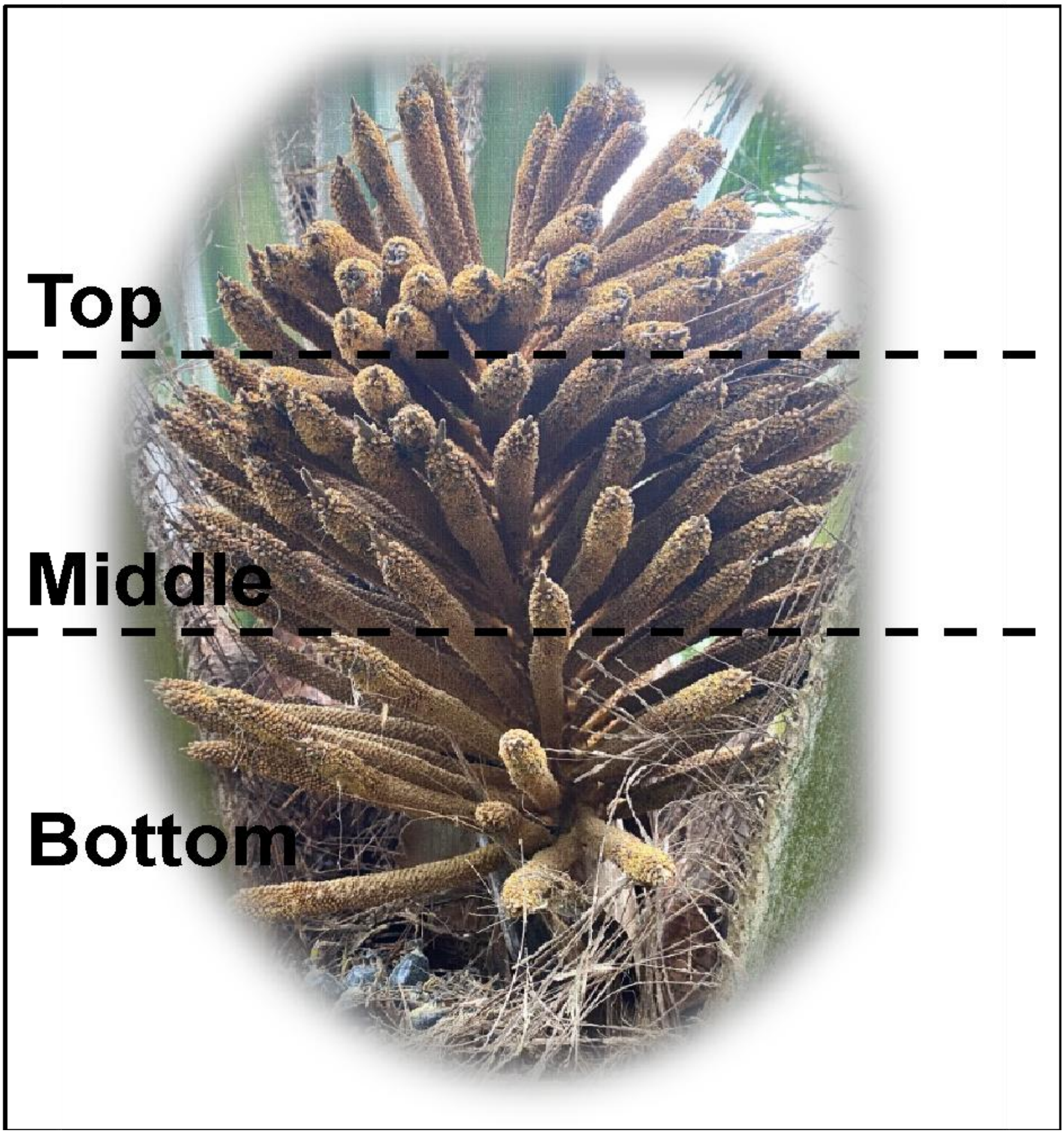

Figure 1. Representative diagram showing the top, middle, and bottom sections of anthesising male inflorescence

Environmental Data Collection

Environmental data (i.e., temperature and relative humidity) were collected daily alongside *E. kamerunicus* sampling. This simultaneous collection ensured a precise correlation between the environmental factors and population density measurements. Daily rainfall data were obtained from the plantation's weather station. Temperature and relative humidity were measured using an Extech 45170 4-in-1 Environmental Meter.

Statistical Analysis

Prior to statistical analysis, the population density per spikelet data were assessed for normality. As these data exhibited a non-normal distribution and resisted successful transformation, Kruskal-Wallis non-parametric analysis was employed to examine the *E. kamerunicus* population density per spikelet. Post-hoc analysis was then conducted using the Dwass, Steel, Critchlow-Fligner (DSCF) method pairwise means comparison**.** Spikelet length was analysed using Analysis of Variance (ANOVA)**,** with Least Significant Difference (LSD) post-hoc analysis applied at a 5% significance level. A correlation study was also performed to investigate the relationship between the weevil population and abiotic variables. All statistical analyses were conducted using SAS 9.4 software**.**

RESULTS

Influence of Spikelet Position of Anthesising Male Inflorescence on Weevil Population Density

On mineral soil, spikelet position significantly influenced ($P<0.05$) on the population densities of female and total *E. kamerunicus* per spikelet during the initial day of anthesis. A significant effect was specifically observed for female weevils per spikelet χ^2=8.2622, $P<0.05$ and for total weevils per spikelet χ^2=8.3139, $P<0.05$. Conversely, the population density of male weevils per spikelet did not exhibit a significant difference concerning spikelet position. These findings are comprehensively detailed in Table 1. Collectively, the results suggest that on mineral soil, the weevil population density per spikelet was less profoundly influenced by spikelet position throughout the anthesis period (Table1).

On the 1st day of anthesis in mineral soil, the highest weevil population density was recorded at the bottom spikelet position. Mean densities were 14.38±2.24 for female weevils, 2.42±0.41 for male weevils, and 16.79±2.59 for total weevils. Conversely, the lowest population was consistently observed on the top spikelet position (Table 1). Individual pairwise comparisons (Table 2) showed a significant difference ($P<0.05$) between the top and bottom spikelet positions, indicating a notably greater weevil population in the bottom position. Specifically, the weevil population density per spikelet in the bottom spikelet was 1.7 times higher than that in the top spikelet position. However, no significant difference was found between the top and middle spikelet positions for either female or total weevil populations per spikelet. Post-hoc analysis for the weevil population on the 1st day of anthesis in mineral soil is further detailed in Table 2.

Table 1. Overall *Elaeidobius kamerunicus* population density per spikelet categorised by soil type, day of anthesis, and spikelet position

Soil Type	**Anthesis Day**	**Spikelet Position**	**Kruskal-Wallis Test Between Weevil Population Density and Spikelet Position**						**Mean Population Density of *E. kamerunicus*/Spikelet**		
			Female Weevil		**Male Weevil**		**Total Weevil**		**Female Weevil ±Std Error**	**Male Weevil ±Std Error**	**Total Weevil ±Std Error**
Mineral	1	Bottom	χ^2	8.2622	χ^2	5.5722	χ^2	8.3139	14.38 ± 2.24	2.42 ± 0.41	16.79 ± 2.59
		Middle	*DF*	2	*DF*	2	*DF*	2	9.81 ± 1.82	2.21 ± 0.4	12.02 ± 2.17
		Top	*P*-value	0.0161*	*P*-value	0.0617	*P*-value	0.0157*	8.38 ± 2.16	1.29 ± 0.33	9.67 ± 2.48
	2	Bottom	χ^2	2.1771	χ^2	0.761	χ^2	1.9513	26.79 ± 4.41	5.63 ± 0.98	32.42 ± 5.32
		Middle	*DF*	2	*DF*	2	*DF*	2	32.94 ± 3.92	6.04 ± 0.85	38.98 ± 4.66
		Top	*P*-value	0.3367	*P*-value	0.6835	*P*-value	0.377	26.23 ± 2.95	5.17 ± 0.7	31.4 ± 3.56
	3	Bottom	χ^2	0.9289	χ^2	0.9482	χ^2	0.7069	49.17 ± 5.8	9 ± 1.28	58.17 ± 6.95
		Middle	*DF*	2	*DF*	2	*DF*	2	50.33 ± 4.95	8.5 ± 1.1	58.83 ± 5.81
		Top	*P*-value	0.6285	*P*-value	0.6224	*P*-value	0.7023	43.79 ± 4.77	7.25 ± 0.96	51.04 ± 5.48
	4	Bottom	χ^2	0.3459	χ^2	0.4947	χ^2	0.2849	17.56 ± 1.82	2.94 ± 0.34	20.5 ± 2.1
		Middle	*DF*	2	*DF*	2	*DF*	2	21.88 ± 2.8	3.33 ± 0.56	25.21 ± 3.26
		Top	*P*-value	0.8412	*P*-value	0.7809	*P*-value	0.8672	22.54 ± 3	3.4 ± 0.53	25.94 ± 3.41
	5	Bottom	χ^2	0.0141	χ^2	0.1126	χ^2	0.0227	2.06 ± 0.59	0.42 ± 0.17	2.48 ± 0.73
		Middle	*DF*	2	*DF*	2	*DF*	2	3.06 ± 0.92	0.52 ± 0.18	3.58 ± 1.08
		Top	*P*-value	0.993	*P*-value	0.9453	*P*-value	0.9887	3.31 ± 1.01	0.52 ± 0.18	3.83 ± 1.12
Peat	1	Bottom	χ^2	1.2356	χ^2	1.6442	χ^2	2.3013	1.73 ± 0.41	0.39 ± 0.09	2.11 ± 0.48
		Middle	*DF*	2	*DF*	2	*DF*	2	2.36 ± 0.72	0.55 ± 0.24	2.91 ± 0.93
		Top	*P*-value	0.5391	*P*-value	0.4395	*P*-value	0.3164	1.68 ± 0.59	0.43 ± 0.22	2.11 ± 0.79
	2	Bottom	χ^2	1.2554	χ^2	0.4777	χ^2	1.5783	3.45 ± 0.8	0.89 ± 0.26	4.34 ± 1.02
		Middle	*DF*	2	*DF*	2	*DF*	2	2.86 ± 0.55	0.59 ± 0.12	3.45 ± 0.6
		Top	*P*-value	0.5338	*P*-value	0.7875	*P*-value	0.4542	2.68 ± 0.73	0.59 ± 0.15	3.27 ± 0.82
	3	Bottom	χ^2	15.6903	χ^2	12.1259	χ^2	18.2638	7.98 ± 1.29	1.84 ± 0.35	9.82 ± 1.59
		Middle	*DF*	2	*DF*	2	*DF*	2	5.82 ± 0.88	1.34 ± 0.33	7.16 ± 1.12

	Top	*P*-value	0.0004**	*P*-value	0.0023**	*P*-value	0.0001 **	2.66 ± 0.51	0.52 ± 0.11	3.18 ± 0.58
4	Bottom	χ^2	1.185	χ^2	4.1634	χ^2	1.2071	3.25 ± 0.49	0.73 ± 0.14	3.98 ± 0.57
	Middle	*DF*	2	*DF*	2	*DF*	2	3.86 ± 0.53	0.95 ± 0.15	4.82 ± 0.61
	Top	*P*-value	0.5529	*P*-value	0.1247	*P*-value	0.5469	3.91 ± 0.78	1.18 ± 0.17	5.09 ± 0.88
5	Bottom	χ^2	0.3187	χ^2	0.4665	χ^2	0.6748	1.79 ± 0.44	0.31 ± 0.07	2.1 ± 0.48
	Middle	*DF*	2	*DF*	2	*DF*	2	2.58 ± 0.95	0.54 ± 0.15	3.13 ± 1.08
	Top	*P*-value	0.8527	*P*-value	0.792	*P*-value	0.7136	1.33 ± 0.31	0.44 ± 0.13	1.77 ± 0.41

Note: * Significant at $P<0.05$ and ^{NS}Non-significant at $P>0.05$

Table 2. Post-hoc pairwise comparisons of *Elaeidobius kamerunicus* population density per spikelet across spikelet positions on day 1 anthesis at mineral soil

Position of Spikelet	**Population Density of *E. kamerunicus* on 1st day of Anthesis/Spikelet**		
	Male Weevil	**Female Weevil**	**Total Weevil**
		***P*-Value**	
Top vs. Middle	0.0989^{NS}	0.3795^{NS}	0.2561^{NS}
Top vs. Bottom	0.1014^{NS}	0.0142^{*}	0.0141^{*}
Middle vs. Bottom	0.9611^{NS}	0.2172^{NS}	0.3116^{NS}

Note: *Significant at $P<0.05$ and ^{NS}Non-significant at $P>0.05$ using DSCF pairwise method

On peat soil, the weevil population density per spikelet on the 3rd day of anthesis showed a highly significant difference ($P<0.01$) with respect to spikelet position. This significance was observed for female weevil at $\chi^2=15.6903$, $P<0.01$, male weevil at $\chi^2=12.1259$, $P<0.01$ and total weevil at $\chi^2=18.2638$, $P<0.01$. Conversely, no significant difference was observed between spikelet position and weevil population density per spikelet on other anthesis days. A summary of these results is presented in Table 1.

During the 3rd day of anthesis in peat soil, the highest weevil population density per spikelet was recorded on the bottom spikelet, with mean densities of 7.98±1.29 for female weevils, 1.84±0.35 for male weevils, and 9.82±1.59 for total weevils. The lowest population was consistently observed on the top spikelet position. These results are also presented in Figure 2 and Table 1. Post-hoc analysis, detailed in Table 3, revealed a highly significant difference ($P<0.01$) between the top and middle spikelet positions for both female and total weevil populations per spikelet. Furthermore, pairwise comparisons between the top and bottom spikelet positions showed a highly significant difference ($P<0.01$) for male, female, and total weevil population densities per spikelet. These findings collectively indicate that the highest weevil congregation occurred on the bottom spikelet position, which was comparatively greater than both the top and middle spikelet positions. Specifically, the weevil population density per spikelet was 3 times greater in the bottom spikelet compared to the top spikelet position.

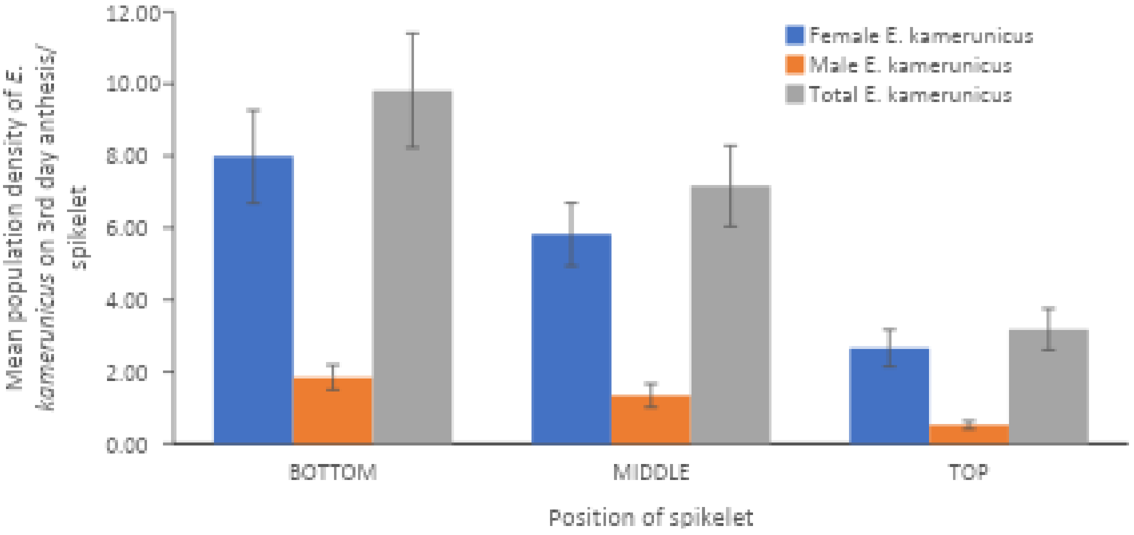

Figure 2. Effect of spikelet position on mean *E. kamerunicus* population density per spikelet during 3rd day of anthesis on peat soil

Table 3. Post-hoc pairwise comparisons of *Elaeidobius kamerunicus* population density per spikelet across spikelet positions on day 3 anthesis at peat soil

Position of Spikelet	**Population Density of *E. kamerunicus* on 3rd Day Anthesis/Spikelet**		
	Male Weevil	**Female Weevil**	**Total Weevil**
		***P*-Value**	
Top vs. Middle	0.2017NS	0.0037**	0.0025**
Top vs. Bottom	0.0013**	0.0012**	0.0003**
Middle vs. Bottom	0.2024NS	0.6373NS	0.6006NS

Note: **Highly significant at *P<0.01* and NSNon-significant at *P>0.05* using DSCF pairwise method

Effect of Soil Type and Spikelet Position on Spikelet Length

The interaction between soil type and spikelet position did not significantly influence spikelet length (*DF*=2, F-value=2.15, *P>0.05*). This suggests that spikelet length isn't determined by the combined effect of these two factors. However, soil type alone significantly affected spikelet length (*DF*=1, F-value=22.65, *P<0.01*). This indicates that spikelet length is indeed influenced by the soil type. Specifically, mineral soil recorded significantly longer spikelets at an average 14.84±0.1 cm compared to peat soil at an average 14.15±0.12 cm. These results are presented in Figure 3.

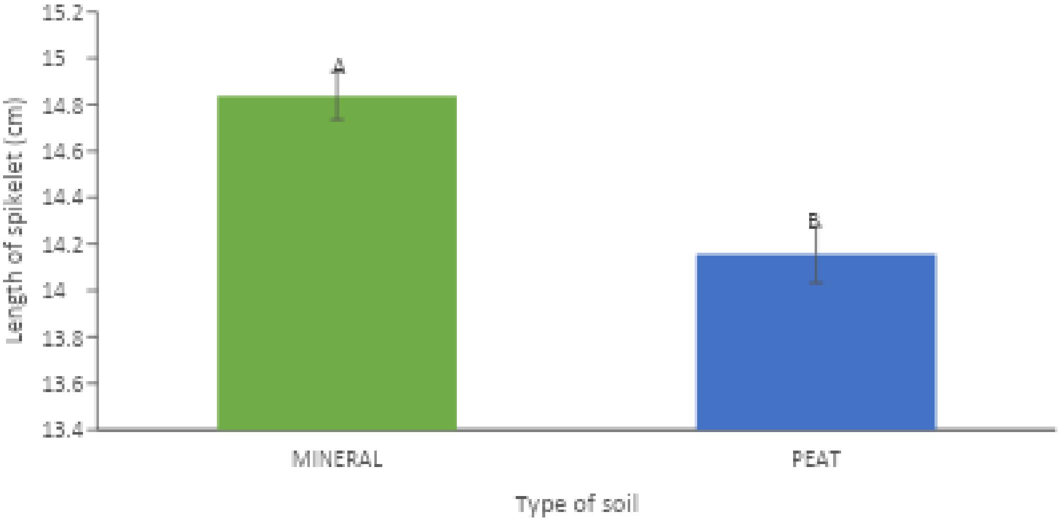

Figure 3. Mean spikelet length across different soil types. Means with similar letters are not significantly different at *P>0.05* using LSD

Spikelet length was also significantly influenced by spikelet position (*DF*=1, *F*-value=151.42, *P<0.01*). Post-hoc analysis revealed that the middle and bottom spikelet positions differed significantly from the top spikelet position. However, no discernible difference was observed between the middle and bottom spikelet positions. This indicates that the bottom and middle spikelet positions exhibited longer spikelet lengths compared to the top. The average lengths are presented in Figure 4: the bottom spikelet at 15.43±0.13 cm, the middle spikelet at 15.35±0.12 cm, and the top spikelet at 12.75±0.13 cm.

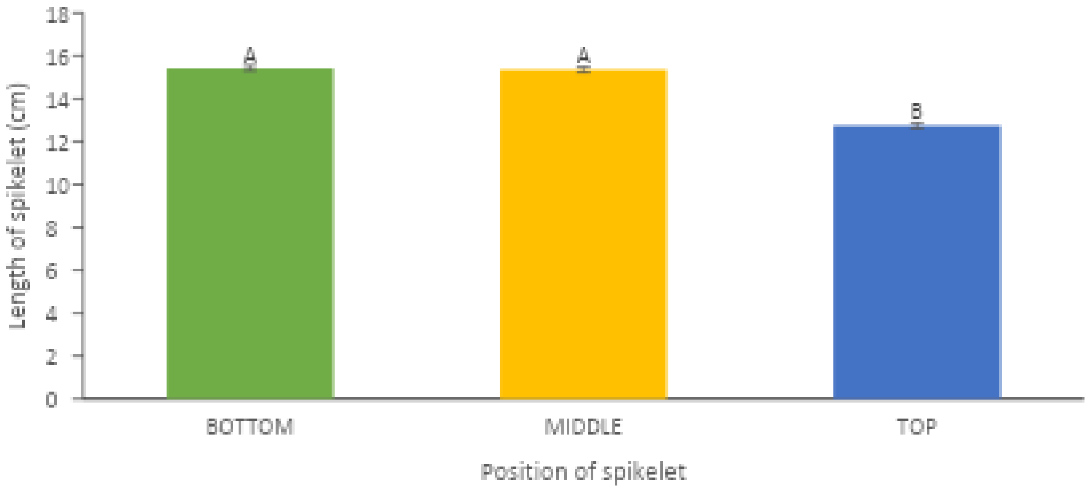

Figure 4. Mean spikelet length across different spikelet positions. Means with similar letters are not significantly different at $P>0.05$ using LSD

Correlation of Abiotic Factors and Spikelet Length with *E. kamerunicus* Population Density

On mineral soil, specific correlations were observed between weevil population density, relative humidity, temperature, and spikelet length across different anthesising days and spikelet positions. During the 2nd day of anthesis, the bottom spikelet position showed a significant, positive, and weak correlation between relative humidity and weevil population density per spikelet. This correlation was evident for female weevils ($r=0.303$, $P<0.05$) and total weevils ($r=0.299$, $P<0.05$). For the middle spikelet position on the 2nd day, relative humidity also exhibited a positive and weak correlation with the male weevil population ($r=0.326$, $P<0.05$). These findings indicate that an increase in relative humidity correlated with an increase in the respective weevil populations. Furthermore, spikelet length recorded a significant, positive, and weak correlation with female weevil density ($r=0.344$, $P<0.05$) and total weevil density ($r=0.33$, $P<0.05$) on the top spikelet position during the 2nd day of anthesis. The positive correlation suggests that increased female and total weevil populations can be associated with longer top spikelets.

On the 3rd day of anthesis, the middle spikelet position recorded a significant, weak, and positive correlation between relative humidity and weevil population per spikelet (female weevil: $r=0.304$, $P<0.05$; total weevil: $r=0.291$, $P<0.05$). Similarly, the top spikelet position showed a significant, positive, and weak correlation between relative humidity and male weevil population ($r=0.351$, $P<0.05$). Moreover, a highly significant, positive, and weak correlation was found between relative humidity and female weevil population ($r=0.374$, $P<0.01$) and total weevil population ($r=0.387$, $P<0.01$) at this position. These results collectively indicate that an increase in relative humidity corresponded to an increase in weevil populations. Additionally, on the 3rd day of anthesis, temperature exhibited a significant, negative, and weak correlation ($P<0.05$) with male weevil ($r=-0.310$), female weevil ($r=-0.358$), and total weevil ($r=-0.366$) populations. Thus, the negative correlation showed that an increase in temperature was associated with a reduction in weevil population density per spikelet.

At the 4th day of anthesis on mineral soil, temperature showed a significant, positive, and weak correlation ($P<0.05$) with female and total weevil populations per spikelet. Specifically, for the bottom spikelet, the correlation was $r=0.305$ for female weevil population and *r=0.300* for total weevil population. On the top spikelet, the correlation was *r=0.304* for female weevil population and *r=0.284* for total weevil population, indicating that an increase in temperature correlated with an increase in female and total weevil populations. Furthermore, spikelet length recorded a significant positive correlation with male weevil population per spikelet (*r=0.59*, *P<0.01*) and total weevil population per spikelet (*r=0.286*, *P<0.05*) on the top spikelet position during the 4th day of anthesis. This suggests that the longer length of top spikelet was associated with higher number of male and total weevil populations. Relative humidity was recorded as having a significant, positive and weak correlation with the middle spikelet male weevil population (*r=0.338*, *P<0.05*).

All other correlations between the studied factors did not show a significant relationship, and these results are summarised in Table 4. Overall, on mineral soil, relative humidity, spikelet length, and temperature were the primary factors influencing weevil population density per spikelet, with their effects varying according to spikelet position and anthesis day.

Table 4. Influence of spikelet length, temperature, relative humidity and rainfall on *Elaeidobius kamerunicus* population density per spikelet in mineral soil

Soil Type	**Anthesising Day**	**Spikelet Position**		**Population Density of *E. kamerunicus*/Spikelet**		
				Male Weevil	**Female Weevil**	**Total Weevil**
				r	***r***	***r***
Mineral	1	Bottom	Length of Spikelet	-0.241	-0.213	-0.223
			Temperature	-0.035	0.055	0.042
			Relative Humidity	0.122	0.038	0.052
			Rainfall	-0.260	-0.224	-0.234
		Middle	Length of Spikelet	-0.034	-0.076	-0.070
			Temperature	-0.175	-0.137	-0.147
			Relative Humidity	0.222	0.284	0.279
			Rainfall	-0.105	-0.189	-0.178
		Top	Length of Spikelet	0.112	0.170	0.163
			Temperature	-0.036	-0.060	-0.058
			Relative Humidity	0.228	0.262	0.258
			Rainfall	-0.138	-0.125	-0.127
	2	Bottom	Length of Spikelet	0.185	0.153	0.161
			Temperature	-0.010	-0.102	-0.086
			Relative Humidity	0.258	0.303*	0.299*
			Rainfall	0.185	0.027	0.057
		Middle	Length of Spikelet	-0.197	-0.071	-0.096
			Temperature	-0.239	-0.170	-0.187
			Relative Humidity	0.326*	0.195	0.224
			Rainfall	0.089	0.006	0.021
		Top	Length of Spikelet	0.235	0.344*	0.330*
			Temperature	0.083	-0.069	-0.041
			Relative Humidity	-0.046	0.030	0.016
			Rainfall	0.005	-0.059	-0.048
	3	Bottom	Length of Spikelet	0.142	0.036	0.056
			Temperature	0.036	-0.090	-0.068

Soil Type	**Anthesising Day**	**Spikelet Position**		**Population Density of *E. kamerunicus*/Spikelet**		
				Male Weevil	**Female Weevil**	**Total Weevil**
				r	***r***	***r***
			Relative Humidity	0.068	0.105	0.100
			Rainfall	.	.	.
		Middle	Length of Spikelet	0.167	0.208	0.209
			Temperature	-0.099	-0.271	-0.250
			Relative Humidity	0.171	0.304*	0.291*
			Rainfall	.	.	.
		Top	Length of Spikelet	-0.015	0.034	0.027
			Temperature	-0.310*	-0.358*	-0.366*
			Relative Humidity	0.351*	0.374**	0.387**
			Rainfall	.	.	.
	4	Bottom	Length of Spikelet	0.263	0.266	0.273
			Temperature	0.226	0.305*	0.300*
			Relative Humidity	0.149	0.043	0.062
			Rainfall	.	.	.
		Middle	Length of Spikelet	-0.030	0.047	0.036
			Temperature	0.008	0.163	0.142
			Relative Humidity	0.338*	0.232	0.257
			Rainfall	.	.	.
		Top	Length of Spikelet	0.359**	0.262	0.286*
			Temperature	0.113	0.304*	0.284*
			Relative Humidity	-0.169	-0.242	-0.239
			Rainfall	.	.	.
	5	Bottom	Length of Spikelet	-0.062	-0.207	-0.182
			Temperature	0.101	0.076	0.085
			Relative Humidity	-0.045	-0.086	-0.080
			Rainfall	.	.	.
		Middle	Length of Spikelet	0.241	0.179	0.193
			Temperature	0.104	0.110	0.111

Soil Type	Anthesising Day	Spikelet Position		Population Density of *E. kamerunicus*/Spikelet		
				Male Weevil	**Female Weevil**	**Total Weevil**
				r	***r***	***r***
			Relative Humidity	-0.109	-0.052	-0.063
			Rainfall	.	.	.
		Top	Length of Spikelet	0.082	-0.140	-0.112
			Temperature	-0.069	-0.097	-0.098
			Relative Humidity	0.186	0.097	0.118
			Rainfall	.	.	.

Note: * Significant at *P<0.05* and **Highly-significant at *P<0.01*

On peat soil, correlation analysis (Table 5) primarily revealed a significant relationship between spikelet length and weevil population density per spikelet. Abiotic factors during the anthesising period and across spikelet positions generally did not significantly influence weevil population density, with one exception: temperature on the 2nd day of anthesis at the top spikelet showed a significant negative and weak correlation ($r=-0.336$, $P<0.05$) with the male weevil population density per spikelet. Regarding spikelet length, specific positive correlations were observed at the top spikelet position across several anthesising days. On the 1st day of anthesis, the length of the top spikelet correlated significantly with the female weevil population ($r=0.365$, $P<0.05$) and total weevil population ($r=0.341$, $P<0.05$). On the 2nd day of anthesis, male ($r=0.355$, $P<0.05$), female ($r=0.358$, $P<0.05$), and total ($r=0.386$, $P<0.05$) weevil populations all showed a significant positive correlation with the length of the top spikelet. Subsequently, on the 3rd day of anthesis, the female ($r=0.320$, $P<0.05$) and total ($r=0.339$, $P<0.05$) weevil populations per spikelet demonstrated a significant positive and weak correlation with the length of the top spikelet. These findings indicate that, on peat soil, the top spikelet position significantly influenced weevil population density through its correlation with spikelet length. Specifically, longer spikelet length was associated with higher a weevil population density per spikelet.

Table 5. Influence of spikelet length, temperature, relative humidity and rainfall on *Elaeidobius kamerunicus* population density per spikelet in peat soil

Soil Type	**Anthesising Day**	**Spikelet Position**		**Population Density of *E. kamerunicus*/Spikelet**		
				Male Weevil	**Female Weevil**	**Total Weevil**
				r	***r***	***r***
Peat	1	Bottom	Length of Spikelet	0.160	-0.102	-0.057
			Temperature	0.048	-0.023	-0.011
			Relative Humidity	-0.135	0.043	0.011
			Rainfall	.	.	.
		Middle	Length of Spikelet	0.063	-0.027	-0.005
			Temperature	-0.084	-0.063	-0.071
			Relative Humidity	0.153	0.165	0.168
			Rainfall	.	.	.
		Top	Length of Spikelet	0.249	0.365*	0.341*
			Temperature	0.228	0.224	0.230
			Relative Humidity	-0.173	-0.138	-0.150
			Rainfall	.	.	.
	2	Bottom	Length of Spikelet	0.087	0.170	0.155
			Temperature	-0.022	-0.003	-0.008
			Relative Humidity	0.106	0.099	0.105
			Rainfall	.	.	.
		Middle	Length of Spikelet	0.023	0.013	0.017
			Temperature	-0.197	-0.004	-0.044
			Relative Humidity	0.107	0.264	0.264
			Rainfall	.	.	.
		Top	Length of Spikelet	0.355*	0.358*	0.386*
			Temperature	-0.336*	-0.245	-0.281
			Relative Humidity	0.201	0.228	0.241
			Rainfall	.	.	.
	3	Bottom	Length of Spikelet	-0.045	-0.034	-0.037
			Temperature	0.037	0.042	0.043

Soil Type	**Anthesising Day**	**Spikelet Position**		**Population Density of *E. kamerunicus*/Spikelet**		
				Male Weevil	**Female Weevil**	**Total Weevil**
				r	***r***	***r***
			Relative Humidity	0.010	0.041	0.036
			Rainfall	.	.	.
		Middle	Length of Spikelet	0.251	-0.007	0.068
			Temperature	-0.251	-0.201	-0.230
			Relative Humidity	-0.010	0.079	0.059
			Rainfall	.	.	.
		Top	Length of Spikelet	0.279	0.320*	0.339*
			Temperature	-0.141	0.035	0.005
			Relative Humidity	0.035	-0.028	-0.018
			Rainfall	.	.	.
	4	Bottom	Length of Spikelet	0.169	0.246	0.250
			Temperature	-0.060	-0.094	-0.094
			Relative Humidity	-0.139	-0.189	-0.194
			Rainfall	.	.	.
		Middle	Length of Spikelet	-0.052	0.134	0.104
			Temperature	0.013	0.233	0.206
			Relative Humidity	0.032	0.010	0.016
			Rainfall	.	.	.
		Top	Length of Spikelet	0.140	0.253	0.252
			Temperature	0.038	0.032	0.036
			Relative Humidity	0.073	-0.020	-0.004
			Rainfall	.	.	.
	5	Bottom	Length of Spikelet	0.136	0.071	0.086
			Temperature	-0.193	-0.132	-0.150
			Relative Humidity	0.257	0.263	0.281
			Rainfall	.	.	.
		Middle	Length of Spikelet	0.112	0.155	0.152
			Temperature	0.006	0.065	0.058

Soil Type	**Anthesising Day**	**Spikelet Position**		**Population Density of *E. kamerunicus*/Spikelet**		
				Male Weevil	**Female Weevil**	**Total Weevil**
				r	***r***	***r***
			Relative Humidity	0.091	0.058	0.064
			Rainfall	.	.	.
		Top	Length of Spikelet	-0.002	0.105	0.079
			Temperature	-0.196	-0.109	-0.146
			Relative Humidity	0.216	0.157	0.189
			Rainfall	.	.	.

Note: * Significant at *P<0.05* and **Highly-significant at *P<0.01*

DISCUSSION

Oil palm male inflorescences significantly impact pollinator weevil populations by providing breeding and feeding grounds, which aid in their development. The support of weevil development by the male inflorescence was initially reported by Syed (1981a) through the observation of a consortium of pollinators in oil palm male inflorescences in Cameroon. This ultimately contributed to the global introduction of *E. kamerunicus* as the pollinating weevil for other oil palm-producing countries, mainly in Southeast Asia. Malaysia introduced *E. kamerunicus* from Cameroon in 1982 to boost fresh fruit bunch production (Syed et al. 1982), which helped propel Malaysia into one of the largest producers of palm oil in the world.

Phenological studies of oil palm from vegetative to bunch production indicate that male inflorescence anthesis is described as a flower opening from the base at 70% on each spikelet, along with the presence of pollen in the anther and the release of an anise-like smell (Forero et al. 2012; Mubarok et al. 2022). This is described as the phenological stage PS607. The anise-like smell is due to the release of the volatile organic compound (VOC) known as estragole, or scientifically as 1-methoxy-4-(2-propenyl) benzene (Lajis et al. 1985). During the male inflorescence anthesis, the third day of anthesis has been reported as the main congregation period for the weevil population. The peak population density was documented during the third day of anthesis in studies conducted worldwide, including in China (Yue et al. 2015), Indonesia (Permana et al. 2021), India (Saravanan et al. 2024) and Malaysia (Swaray et al. 2021). The original study in Cameroon also documented a similar finding (Syed 1981a). In this study, the average peak population density can also be viewed during the third day of anthesis in both mineral and peat soil. This shows that the characteristic of the weevil congregation remains similar regardless of region or soil type.

The distribution of adult *E. kamerunicus* weevils on male inflorescence showed a distinct pattern across the spikelet positions. In peat soil at Sarawak, a significant difference was recorded in the average number of weevils across the spikelet positions (Mohamad et al. 2021b). The top spikelet position recorded fewer weevils, between 11 and 13 weevils per spikelet, and was significantly different compared to the middle and bottom spikelet positions, which had more than 20 weevils per spikelet. On the contrary, the weevil populations in the middle and bottom spikelet positions were not significantly different (Mohamad et al. 2021b). The study also observed that the weevil population in mineral soil did not show significant differences with regard to the different spikelet positions. Mohamad et al. (2021b) suggested this is because mineral soils support better oil palm growth and inflorescence development. Referring to the previously reported study, this study on peat soil also recorded similar occurrence during the 3rd day of male inflorescence anthesis, where the male, female, and total weevil populations per spikelet were significantly different with regard to the spikelet position. Further analysis revealed significant differences in weevil populations, with the top spikelet position having a lower average number compared to the middle and bottom spikelet positions. Similarly, the weevil population in the mineral soil cultivated area was not affected. Summarising from the reported and this study, the weevil population on peat soil was influenced by the spikelet position.

The male oil palm inflorescence exhibits a distinct opening pattern where anthesis begins sequentially from the base of each spikelet (Forero et al. 2012; Mubarok et al. 2022). Each spikelet is densely packed, containing 400 to 1,500 florets (Yaakub et al. 2023), which are the source for starchy pollen grains as food sourced (Tandon et al. 2001) and breeding sites for the pollinating weevil, *E. kamerunicus* (Syed 1979). The longer spikelets typically found in the middle and basal (bottom) sections of the inflorescence likely support a greater weevil population because they offer both more substantial food resources and increased oviposition sites. Ponnamma et al. (2006) recorded a significant positive correlation between spikelet length and the number of emerged adults. This indicates that longer spikelets act as an incentive for the weevils, providing superior food sources and breeding sites. Additionally, as these basal spikelets open earlier than those at the apex, they provide a temporal advantage in resource availability. Conversely, post-anthesis spikelets cease to be visited by the weevils due to the lack of required food sources (Tandon et al. 2001).

Soil type has been reported to influence the characteristics of male oil palm inflorescences. In Borneo peat soil, significant differences in spikelet length were observed with respect to spikelet position. Specifically, the top spikelets recorded the shortest length of spikelet and were significantly different compared to the middle and bottom spikelets (Mohamad et al. 2021b). However, this result was not observed in male inflorescences at mineral soil. Furthermore, the study also reported similar spikelet lengths for the bottom and middle positions in peat soil cultivated areas, with no significant differences recorded (Mohamad et al. 2021b). While this study did not replicate the previous findings, we did observe significant differences in spikelet length between mineral and peat soils. Notably, longer spikelets were measured in male inflorescences at mineral soil. Overall, this study results also confirmed that the top spikelet position had the shortest spikelets and was significantly different compared to the middle and bottom positions. This suggests that spikelet length is influenced by soil type.

During the peak anthesis of male inflorescence, abiotic factors have been shown to influence weevil populations. Saravanan et al. (2024) reported that relative humidity was not correlated with weevil activity during anthesis. In contrast, maximum and minimum temperatures showed a strong and negative correlation with weevil activity during male inflorescence anthesis. Their study observed this pattern in oil palm integrated with cocoa in India. In Indonesia, the abundance of weevils on male inflorescences was reported to be positively correlated with temperature and negatively correlated with humidity, both exhibiting a moderate relationship (Permana et al. 2021). In this study, however, the effect of temperature and relative humidity on Day 3 of male inflorescence anthesis varied in response to spikelet position. Nevertheless, the observed correlations were generally weak. Furthermore, peat soil was recorded unaffected by the temperature and relative humidity factor. It can be concluded that relative humidity and temperature can yield varied results, thus necessitating thorough modelling to predict their influence on weevil populations. The influence of abiotic factors extends beyond adult weevil activity to the next generation. A separate study on weevil emergence (the precursor to population build-up) reported that it was positively influenced by the number of rainy days and RH, yet negatively influenced by maximum temperature (Dhileepan 1994). Interestingly, rainfall amount itself was not correlated with emergence (Dhileepan 1994). This suggests that abiotic conditions directly influence the survival of developing larvae and pupae, thereby affecting the size of the subsequent adult population.

Previous studies present an unclear correlation between rainfall and *E. kamerunicus* weevil populations (Donough et al. 1996). In fact, the weevil population and activity often remain high even during wet seasons, with significant activity recorded despite monthly rainfall reaching 300 mm (Wahid & Kamarudin 1997) and a high population sustained at 400 mm (Dhileepan 1994). However, researchers concur that the intensity of rainfall over a prolonged period can negatively impact pollination by reducing pollen viability (Donough et al. 1996) and that an increased number of rainy days correlates with reduced fruit set (Dhileepan 1994).

Conversely, some findings suggest that the population build-up for *E. kamerunicus* occurs during the dry season, specifically when monthly rainfall accumulates to less than 120 mm (Cik Mohd Rizuan et al. 2013). Therefore, while weevils can tolerate heavy rain for activity, prolonged high rainfall may hinder the optimal population increase required for effective pollination. For this study, however, we could not assess this correlation, as the study area experienced no rainfall during the sampling period, precluding any reporting on this variable.

Male inflorescences release volatile organic compounds (VOCs), predominantly estragole, which act as the primary olfactory cue for pollinating weevils. Recent chromatographic analyses reveal that estragole emissions vary significantly by soil type, with inflorescences on peat soil emitting the highest concentrations (156.2 ppm), followed by mineral (136.8 ppm) and clay soils (110.3 ppm) (Fahmi-Halil et al. 2025). However, *E. kamerunicus* possesses a strict attraction threshold for this compound. Laboratory studies demonstrate that attraction peaks significantly at a 100 ppm concentration, drawing nearly 50% of the weevils (Muhamad-Fahmi et al. 2024). At higher concentrations of 150 and 200 ppm, attraction sharply decreases because the intense aroma overstimulates and impairs the weevils' sensory functions. This indicates that while estragole is a key factor influencing weevil behaviour, no studies have yet reported its actual field emissions during anthesis, nor its direct effect on population density across different soil types.

During the third day of male inflorescence anthesis, a relationship was observed between the number of weevils and spikelet length, specifically in relation to spikelet position in peat soil in Sarawak. The findings by Mohamad et al. (2021b) indicated a highly significant relationship across all spikelet positions in peat soil in Roban, Sarawak, and at the bottom spikelet position in peat soil in Pusa, Sarawak. This study reported a positive and weak correlation between the mean number of weevils and spikelet length. In contrast, mineral soil showed no significant correlation. Consistent with previous studies, the present study on peat soil in Pahang also exhibited a significant, positive, and weak correlation between spikelet length and weevil population density, but only at the top spikelet position. Furthermore, this study found a significant relationship between all male, female, and total weevil population densities during this period. Mineral soil, however, did not record a relationship during the peak inflorescence anthesis. Comparative results from both studies suggest that shorter spikelet length at the top spikelet position may influence weevil population density.

The contrasting soil properties of peat and mineral soils likely exert a strong influence on the observed differences in both spikelet characteristics and weevil distribution. Peat soils, prevalent in regions like Sarawak and parts of Peninsular Malaysia, are characterised by their high organic matter content, which leads to low bulk density and high-water retention (Md Talib et al. 2025; Pakir et al. 2025; Ratai et al. 2024; Tong & Ling 2015). For instance, peat in Sabah has shown moisture content as high as 687.03% and organic matter up to 98.94% (Md Talib et al. 2025). Similarly, Sarawakian peat exhibits a low bulk density, ranging from 0.14 to 0.3 g/cm^3, and organic matter content reaching over 74% (Tong & Ling 2015). However, high water retention can also result in poor drainage and aeration, creating anaerobic conditions that can limit nutrient availability and root development (Bakri et al. 2025; Santi et al. 2022). Furthermore, peat soils are often acidic and may have lower levels of essential nutrients like phosphorus, potassium, and micronutrients such as zinc and boron compared to mineral soils (Manalu et al. 2024; Sagwal et al. 2023). These soil conditions may indirectly influence inflorescence development and weevil behaviour, perhaps by altering the volatile compounds released by the flowers or affecting spikelet size and structure.

In contrast, mineral soils, derived from the weathering of rocks, generally have a higher mineral content, better drainage and aeration, and a more neutral pH (Weil & Brady 2017). The improved drainage in mineral soils allows for better root growth and nutrient uptake, which can contribute to the enhanced spikelet development we observed. This is because macropores in the soil play a significant role in water infiltration and drainage, and practices that improve soil physical conditions, such as organic matter addition and minimal tillage, lead to increased porosity and water retention, thereby promoting root development and water availability for plants (Pan et al. 2018). For example, agroforestry systems with trees having deep root systems create channels for water infiltration. The differences in soil texture and structure also influence water infiltration and retention, which can affect soil temperature and humidity, potentially creating a more favourable microclimate for weevils on mineral soils. Soil texture, structure, and organic matter content are identified as key factors influencing water infiltration and retention, as well as soil temperature and humidity (Pan et al. 2018). Pan et al. (2018) discuss that management practices that reduce soil temperature can promote water maintenance and reduce evaporation. Where the management practice to help water retention such as additional of organic matter, addition of macrofauna, mulching and crop rotation.

Further research should investigate the specific soil properties that most strongly correlate with spikelet characteristics and weevil population dynamics. This could involve detailed analyses of soil pH, nutrient content, bulk density, water holding capacity, and microbial activity in both peat and mineral soil plantations. Understanding these complex soil-plant-insect interactions could lead to the development of more targeted soil management strategies, such as nutrient amendments or drainage improvements, to promote both healthy palm growth and efficient pollination.

CONCLUSION

This study confirmed that spikelet position significantly influences the population density of *E. kamerunicus* during the anthesising period of male inflorescence in oil palm plantations, with distinct variations observed between peat and mineral soil environments. Notably, the bottom spikelet position consistently supported higher weevil populations compared to the top spikelet, particularly during the 1st day on mineral soil and the 3rd day on peat soil. Spikelet length also varied significantly with both soil type and position, with longer spikelets generally found in mineral soils and in the middle or bottom positions. The longer spikelet supports weevil congregation by providing more extensive breeding sites. Correlation analyses demonstrate that abiotic factors, specifically relative humidity, temperature, and spikelet length, influence *E. kamerunicus* populations. However, this influence is highly variable, often shifting based on the day of anthesis and the spikelet's position on the inflorescence. These factors are generally believed to exert their strongest influence on overall weevil population when they persist over a longer period or multiple months. These findings emphasise the importance of considering microhabitat characteristics and environmental conditions when assessing pollinator dynamics in oil palm cultivation. The insights gained can be applied to monitor the pollinating weevil population and potentially guide agronomic practices for instance pesticide application to avoid the spikelet position that support the greater weevil with end goal to achieve satisfactory fruit set, especially in challenging peat soil environments.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Ethics Declarations

No ethical issue is required for this research

Data Availability Statement

This is a Doctor of Philosophy Project and the data are currently in Ph.D thesis entitled "Population Density and Pollinating Activity of *Elaeidobius kamerunicus* Faust (Coleoptera: Curculionidae) In Mineral and Peat Soil Oil Palm Plantation" (2024).

Authors' Contributions

Muhamad Haziq Hadif Zulkefli, Mohamed Mazmira Mohd Masri and Saharul Abillah Mohamad conceptualized this research and designed experiments; Muhamad Haziq Hadif Zulkefli, Syari Jamian, Sumaiyah Abdullah, Mohamed Mazmira Mohd Masri and Saharul Abillah Mohamad participated in the design and interpretation of the data; Muhamad Haziq Hadif Zulkefli wrote the paper and Syari Jamian, Nur Azura Adam, Sumaiyah Abdullah, Mohamed Mazmira Mohd Masri, Ramle Moslim and Saharul Abillah Mohamad participated in the revisions of it. All authors read and approved the manuscript.

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