

Insect pollinators of oil palm plantations in South Sumatra, Indonesia

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Abstract. Herlinda S, Sari JMP, Lau WH, Anggraini E, Irsan C, Rindiani DE, Nelly N, Lisnawati, Suharjo R. 2025. Insect pollinators of oil palm plantations in South Sumatra, Indonesia. *Biodiversitas* 26: 5595-5611. Information on insect pollinator species of oil palm is crucial for management strategies that support sustainable production. This study aimed to identify pollinator insect species found in South Sumatra, Indonesia, and analyze their species diversity and abundance. Pollinators were sampled from male and female inflorescences at four time intervals (08:00-09:59 a.m., 10:00-11:59 a.m., 02:00-03:59 p.m., and 04:00-05:59 p.m.) using anthesis-based collection methods. The result showed that *Elaeidobius kamerunicus* and *Elaeidobius* spp. were the most common insect pollinators in oil palm production areas, occurring from lowland to midland regions. These species were present on both male and female inflorescences but were more abundant on male inflorescences, with peak activity recorded between 8:00 a.m. and 11:59 a.m. *Apis mellifera* and *A. dorsata* were also observed on both male and female inflorescences, though their activity was generally limited to the morning and midday periods. All species (*E. kamerunicus*, *Elaeidobius* spp., *A. mellifera*, and *A. dorsata*) are potential pollinators, as their visitation of both male and female inflorescences facilitates pollen transfer to the female flowers. Considering the continuous activity of *E. kamerunicus* and *Elaeidobius* spp. throughout the day, the use of contact insecticides in oil palm plantations should be avoided to reduce adverse impacts on pollinator populations. These findings provide baseline data for designing pollinator-friendly management practices in Indonesia's oil palm sector.

Keywords: *Apis cerana*, *Apis mellifera*, *Elaeis guineensis*, *Elaeidobius kamerunicus*, *Heterotrigona itama*

INTRODUCTION

Pest and disease outbreaks are commonly identified by companies and smallholders as major contributors to declining oil palm (*Elaeis guineensis* Jacq.) yields (Anggraini et al. 2024, 2025), along with nutrient deficiencies. Consequently, efforts to increase production are often directed toward higher doses and more frequent applications of fertilizers (Darras et al. 2019). The use of synthetic insecticides for pest and disease management has become increasingly widespread (Norhayu and Nurnisa 2015), while intensive herbicide spraying is also routinely practiced (Darras et al. 2019). However, an important factor influencing oil palm productivity that is frequently overlooked is the role of pollinating insects (Gintoron et al. 2023). Pollinators are highly vulnerable to pesticide exposure, both from herbicides (Darras et al. 2019), which destroy habitats and eliminate alternative floral resources, and from insecticides (Norhayu and Nurnisa 2015), which directly reduce their activity. The negative effects of

synthetic insecticides have been shown to decrease visits of *Elaeidobius kamerunicus* (Faust, 1898) Haran, Beaudoin-Ollivier, Benoit & Kuschel, 2020 to oil palm flowers by 43-83% (Ming et al. 2022). Given the increasing demand for sustainable palm oil, both domestically and internationally, oil palm plantations are expected to adopt environmentally responsible practices and minimize reliance on synthetic fertilizers and pesticides that threaten ecosystem health.

Efforts to enhance sustainable oil palm production in Indonesia through insect pollination have a long history, exemplified by the successful introduction of *E. kamerunicus* from Cameroon, West Africa, in 1981 (Swaray et al. 2021). This introduction significantly improved pollination efficiency and boosted palm oil yields in Indonesia (Li et al. 2019). However, more than four decades later, declines in fresh fruit bunch yields have been reported (Rodzik et al. 2023), attributed to reduced pollination efficiency. This decline is linked to the low genetic diversity of *E. kamerunicus*, a consequence of the

founder effect in newly established populations derived from a limited number of individuals (Prasetyo et al. 2023). Indigenous insect pollinators also play a role but exhibit limitations. *Thrips hawaiiensis* Morgan, 1913, for instance, flies at low levels and is less effective under strong winds and heavy rain. *Pyroderces* spp. are active for only 2-3 hours per day, primarily visiting female inflorescences but pupating on male ones (Gintoron et al. 2023). Stingless bees, such as *Lepidotrigona terminata* Smith, 1878 and *Sundatrigona moorei* Schwarz, 1937, also demonstrate pollination potential, though their activity is strongly influenced by environmental factors such as humidity, temperature, and light intensity. Moreover, they occupy different temporal niches: *Lepidotrigona terminata* is most active from midday to evening (12:00 p.m.-06:00 p.m.), while *S. moorei* is active in the morning (08:00-10:00 a.m.) (Ramadani et al. 2021). Enhancing the efficacy of multi-pollinator systems across both smallholders and industrial plantations remains an important strategy for sustaining oil palm productivity (Angraeni et al. 2013).

In Jambi Province, Indonesia over 36 species of insect pollinators have been recorded on oil palms; however, it remains unclear whether all these species function as true pollinators, as the insect samples were collected using nets (Siregar et al. 2016). Insects captured by netting may exclusively visit either male or female inflorescences, or they may be incidental visitors to oil palm flowers (Auffray et al. 2017). An insect can be classified as an effective pollinator only if it visits both male and female inflorescences, thereby enabling pollen transfer to female flowers (Permana et al. 2017). Conversely, species that visit only male or only female inflorescences cannot be considered pollinators (Gintoron et al. 2023). Accurate determination of pollinator status, therefore, requires sampling from both male and female inflorescences. Information on the composition, diversity, and abundance of insect pollinators in oil palm production areas of South Sumatra is crucial for supporting policy decisions by

plantation companies, including whether to introduce foreign pollinator species, and for guiding conservation strategies targeting native pollinators in both corporate and smallholder plantations. Therefore, this study aimed to identify insect pollinator species found in South Sumatra and analyze their diversity and abundance.

MATERIALS AND METHODS

Survey area

The survey was conducted in oil palm plantations center across South Sumatra Province, Indonesia, covering locations: Banyuasin III (Banyuasin District; 2°54'58"S, 104°25'23"E), Benakat (Muara Enim District; 3°25'37.32074"S, 103°48'21.56465"E), North Indralaya (Ogan Ilir District; 3°12'32.80475"S, 104°38'19.83563"E), Lahat (Lahat District; 3°47'11"S, 103°32'34"E), Lembak (Muara Enim District; 3°20'19.79390"S, 104°20'56.73473"E), Lempuing Jaya (Ogan Komerling Ilir District; 3°47'37.06278"S, 104°53'57.55643"E), Sembawa (Banyuasin District; 2°54'39.21617"S, 104°32'19.54500"E), Sungai Lilin (Musi Banyuasin District; 2°35'19.3"S, 104°6'37.6"E), and Teluk Gelam (Ogan Komerling Ilir District; 3°29'49.12660"S, 104°48'34.69000"E). Oil palm plantations at these sites range from 100 to 500 ha, with survey plots of 2-3 hectares selected at each location. Survey locations were marked in red on the primary map (Figure 1). Altitude variations were represented by color classification, with the lowest altitudes (-79.82 to 200.28 meters above sea level/masl) shown in green, and the highest altitudes (1,588.12 to 3,166.95 masl) shown in red. The inset map illustrated the geographical position of South Sumatra Province on Sumatra Island (top) and delineated the surveyed districts within the province (bottom).

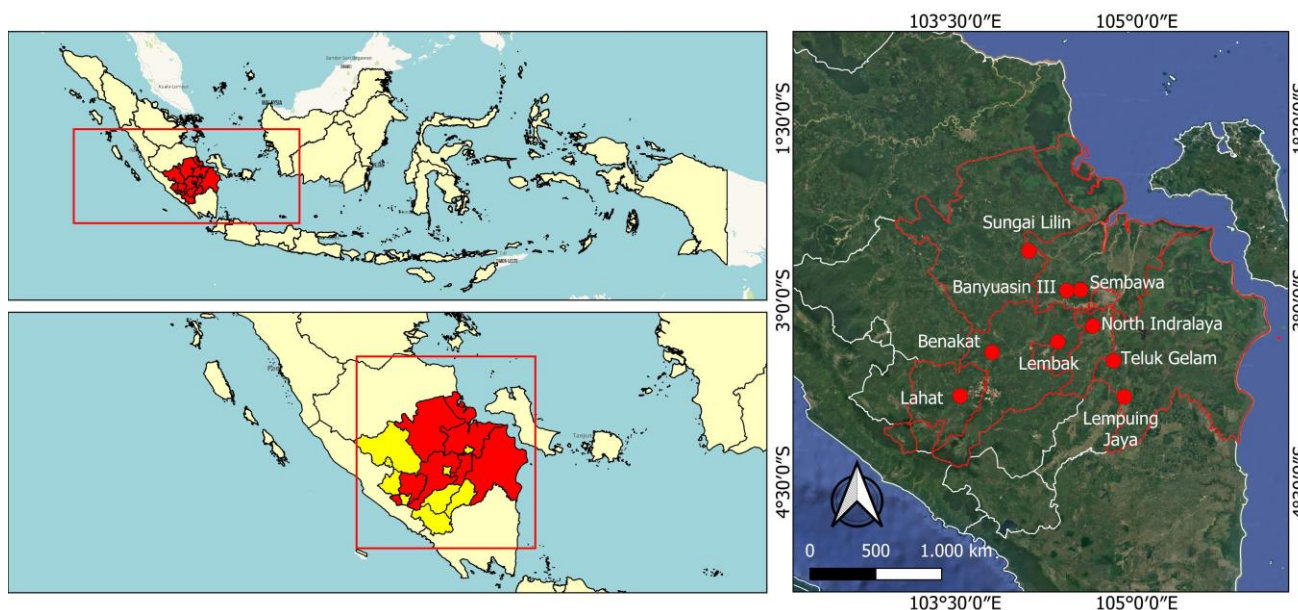


Figure 1. Map of the survey locations for insect pollinators in oil palm plantations, South Sumatra, Indonesia

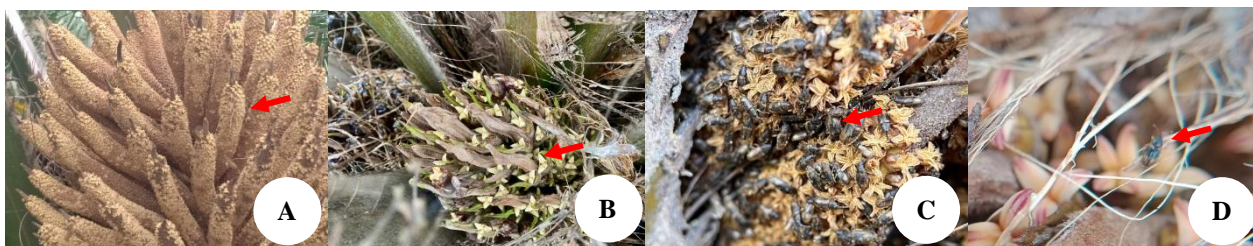


Figure 2. Oil palm flowers: A. Anthesizing male flowers, B. Anthesizing female flowers, C. Insect pollinators on male flower, D. Insect pollinators on female flower

Insect pollinator sampling, observation, and identification

In each sub-district, three plots were selected as replicates for observations. The plot covered an area of approximately 2-3 ha and consisted of mature oil palm plantations aged 3.5-7 years. The surveyed plantations represented both company-owned estates and smallholder farms, with plant selection based on the presence of flowers and fruit. The survey was conducted from May to August 2025. Insect pollinators were collected from both male and female inflorescences, as their presence on both was indicative of a pollination role. Insects found exclusively on either male or female inflorescences were not classified as pollinators (Gintoron et al. 2023). Insect sampling was conducted on anthesis days (Figure 2). For male inflorescences, anthesizing spikelets (20-30 cm in length) were cut, one spikelet per palm, from 15 trees per plantation, with three plantations sampled in each district. Female inflorescences were sampled using a vacuum device (16.8 KPa) to extract visiting insects. The number of insects collected per spikelet or inflorescence was recorded using counters. Inflorescences containing pollinators were placed in labeled plastic containers according to palm number and transported to the laboratory, where pollinators were separated from floral material (Swaray et al. 2021). Sampling was conducted at four daily intervals: 8:00-9:59 a.m., 10:00-11:59 a.m., 2:00-3:59 p.m., and 4:00-5:59 p.m. (Ramadani et al. 2021). Collections were carried out monthly from May to August 2025.

Collected insect pollinator specimens were preserved in vials containing 85% ethanol. Adult insect pollinators were identified based on morphological characteristics following the procedures of Engel et al. (2018) and Haran et al. (2020). Diagnostic features used for identification included the proboscis, body hair, abdominal tergites, antennal flagellum, coloration, wing venation, and thorax structure. Specimens were examined under a Stereo Microscope SZ51 at 30 \times magnification, and images were captured using an OptiLab Advance Plus. The variables observed included insect species and the number of individuals recorded at each time interval (8:00-9:59 a.m., 10:00-11:59 a.m., 2:00-3:59 p.m., and 4:00-5:59 p.m.), as well as species composition and abundance on male and female

inflorescences. Supporting data were also collected, including water management practices, plantation ownership, oil palm age, weed control methods, pest and disease management, fertilizer dosage, presence of wild plants/refugia around plantations, and the altitude of each survey location (Table 1).

Data analysis

The abundance of insect pollinators was checked for normality using the Shapiro-Wilk test and for variance homogeneity using Levene's test. Data were square-root transformed to meet assumptions of normality and homogeneity prior to one-way Analysis of Variance (ANOVA). Mean comparisons were performed using Tukey's HSD (honestly significant difference) test, and results were reported as back-transformed means. Species diversity was assessed using the Shannon-Wiener index (H'), dominance (D), and evenness (E) (Magurran 2004). All statistical analyses were conducted in RStudio (Version 1.4.1106; RStudio). Differences in abundance across observation times, locations, and male versus female inflorescences were visualized using Principal Component Analysis (PCA). The PCA was performed on Hellinger-transformed abundance data to evaluate variations in pollinator community makeup among subdistricts. The Hellinger transformation, which involves taking the square root of relative abundance for each sample site, was utilized to mitigate the dominating effect of prevalent species and to address the occurrence of zero values characteristic of ecological count data. Analyses were conducted using R version 4.3.2 with the vegan package, employing the decostand function for transformation and rda for PCA. The initial two principal components (Dim1 and Dim2) were preserved to encapsulate the primary gradients in species composition. Ordination biplots were produced with the ggplot2 and ggrepel programs, illustrating sampling locations as points and species as vectors. The orientation of each vector signifies the species' relationship with the ordination axes, whereas the magnitude denotes its relative contribution. The proportion of total variation elucidated by each axis was derived from the PCA summary and depicted in the plot.

Table 1. Characteristics of oil palm plantations with different management practices in South Sumatra, Indonesia

Characteristic	Banyuasin III	Benakat	Indralaya Utara	Lahat	Lembak	Lempuing Jaya	Sembawa	Sungai Lilin	Teluk Gelam
Water management	Non-irrigation	Irrigation	Irrigation	Irrigation	Non-irrigated	Irrigation	Non-irrigated	Non-irrigated	Irrigation
Age of oil palm (years)	6	5	4	7	3.5	6	5	5	7
Weed control	Herbicides (glyphosate and paraquat)	Herbicides (glyphosate and paraquat)	Herbicides (glyphosate)	Herbicides (glyphosate)	Herbicides (glyphosate)	Herbicides (glyphosate)	Herbicides (glyphosate and paraquat)	Herbicides (glyphosate and paraquat)	Herbicides (glyphosate)
Plant pest and disease control	Non-pesticides	Insecticide (metomil)	Non-pesticides	Non-pesticides	Non-pesticides	Non-pesticides	Non-pesticides	Non-pesticides	Insecticide (lambda-cyhalothrin)
Fertilizer	N and manure	NPK fertilizers and manure	NPK fertilizers	NPK fertilizers	NPK fertilizers	N fertilizer manure	N fertilizer and manure	NPK fertilizers	NPK fertilizers
Other crops around oil palm plantations	<i>Praxelis clematidea</i> (Griseb.) R.M.King & H.Rob., <i>Spermacoce alata</i> Aubl., and <i>Asystasia gangetica</i> (L.) T.Anderson	<i>Mimosa pudica</i> L., <i>Imperata cylindrica</i> (L.) Raeusch., <i>Paspalum distichum</i> L., <i>Cyperus rotundus</i> L.,	<i>Imperata cylindrica</i> (L.) Raeusch. and <i>Ageratum conyzoides</i> L.	<i>Ageratum conyzoides</i> L., <i>Mimosa pudica</i> L., <i>Imperata cylindrica</i> (L.) Raeusch., <i>Melastoma malabathricum</i> L., <i>Mikania micrantha</i> Kunth, <i>Asystasia gangetica</i> (L.) T.Anderson, <i>Digitaria ciliaris</i> (Retz.) Koeler	<i>Clidemia hirta</i> (L.) D.Don, <i>Ageratum conyzoides</i> L., <i>Clitoria laurifolia</i> Poir., <i>Zornia latifolia</i> Sm., <i>Asystasia gangetica</i> (L.) T.Anderson	<i>Ageratum conyzoides</i> L., <i>Imperata cylindrica</i> (L.) Raeusch., <i>Mimosa pudica</i> L., <i>Cyperus rotundus</i> L., <i>Synedrella nodiflora</i> (L.) Gaertn., <i>Asystasia gangetica</i> (L.) T.Anderson	<i>Mimosa pudica</i> L., <i>Melastoma malabathricum</i> L., <i>Ageratum conyzoides</i> L., <i>Borreria latifolia</i> (Aubl.) K.Schum.	<i>Asystasia gangetica</i> (L.) T.Anderson, <i>Stachytarpheta jamaicensis</i> (L.) Vahl, <i>Nephrolepis cordifolia</i> (L.) C.Presl, <i>Hyptis brevipes</i> Poit., <i>Centotheca lappacea</i> (L.) Desv., <i>Cynodon dactylon</i> (L.) Pers.	<i>Ageratum conyzoides</i> L., <i>Melastoma malabathricum</i> L., <i>Mikania micrantha</i> Kunth, <i>Nephrolepis biserrata</i> (Sw.) Desv., <i>Borreria alata</i> (Aubl.) DC.
Altitude (m)	9	78	7	167	47	25	16	34	19

RESULTS AND DISCUSSION

An abundance of insect pollinators across the oil palm plantation location

The dominant insect pollinator species recorded in oil palm plantations of South Sumatra were *E. kamerunicus*, *Elaeidobius* spp., and honey bees (*Apis cerana* Fabricius, 1793, *Apis dorsata* Fabricius, 1793, and *Apis mellifera* Linnaeus, 1758), each with distinct morphological characteristics (Table 2; Figure 3). Other species were present in low abundance, including *Heterotrigona itama* Cockerell, 1918, *Saula japonica* Gorham, 1874, *Stratiomys potamida* Meigen, 1822, *Zyginidia* sp., and Formicidae (unknown species). Pollinator abundance varied across locations in South Sumatra. *Elaeidobius kamerunicus* and *Elaeidobius* sp. A were consistently abundant, with the highest numbers recorded in Lahat (575.79 and 758.50 individuals per 5 spikelets, respectively) and Lempuing Jaya (682.04 and 376.42 individuals per 5 spikelets), which were significantly higher than abundances in Banyuasin III, Benakat, North Indralaya, Sembawa, and Sungai Lilin ($P = 0.01$). In contrast, *A. cerana* and *A. dorsata* were rare or absent in several locations. *Apis cerana* was detected only in North Indralaya (0.92 individuals/5 spikelets) and Teluk Gelam (0.58 individuals/5 spikelets), while *A. dorsata* was observed infrequently across sites. Other species, including Formicidae (unidentified), *S. potamida*, and *Zyginidia* sp., were scarce and recorded in low numbers at multiple locations.

The PCA biplot revealed distinct differences in the composition and distribution of pollinating insects across sub-districts. The first axis (Dim1=69.55%) and the second axis (Dim2=30.45%) together explained most of the variation in pollinator abundance at the study site (Figure 4). The PCA biplot utilizing Hellinger-transformed data demonstrates distinct differentiation among subdistricts. The primary axis (Dim1=69.55%) delineates the principal gradient in pollinator composition, distinguishing

Elaeidobius-dominated sites (right side of the plot) from those characterized by stingless bees (*H. itama*) and *Apis* spp. (upper region). The second axis (Dim2=30.45%) encapsulates secondary variation associated with the relative abundance of *E. kamerunicus* and *E. A/B* groups. The initial two axes account for 100% of the overall variation, signifying that the majority of community disparities are effectively encapsulated in the ordination. Species of the genus *Elaeidobius* (*E. kamerunicus* and *Elaeidobius* spp.) dominated and occurred across nearly all sub-districts, confirming their role as the primary and widely distributed pollinators. In contrast, *A. dorsata* and *A. mellifera* were more closely associated with the lower left quadrant (negative dimensions), while *S. japonicus* and *Elaeidobius* sp. B clustered toward the positive right dimension, indicating stronger associations with the Benakat Sub-district. Similarly, *H. itama* and unidentified Formicidae were associated with the positive dimension of North Indralaya and its surrounding areas, whereas *Zyginidia* sp. was positioned in the opposite (negative) dimension, reflecting contrasting habitat preferences. Overall, the PCA results demonstrated that although *Elaeidobius* was consistently present and dominant across all sites, certain pollinator species exhibited localized dominance and specialization depending on the sub-district.

Abundance of insect pollinators across four observation periods

Elaeidobius kamerunicus was the dominant pollinator species, occurring consistently across all observation sites (Table 3). Other species from the same genus, including *Elaeidobius* sp. A, B, C, and D were also recorded in relatively high numbers in several sub-districts. Pollinator activity varied with observation time, with most species, particularly *Elaeidobius* spp. showing peak activity between 8:00-9:59 a.m. and 10:00-11:59 a.m., followed by a decline toward midday and evening.

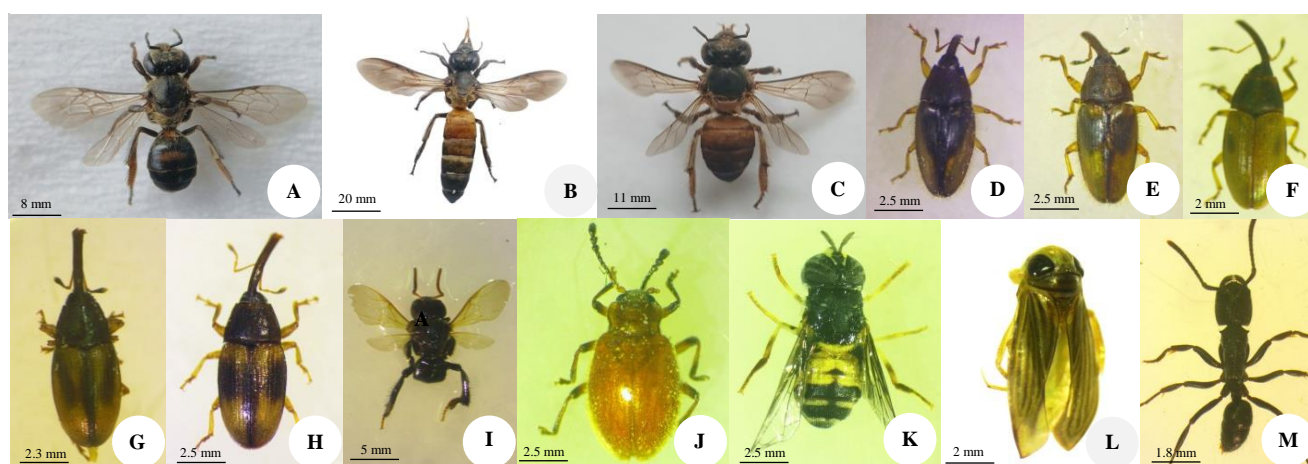


Figure 3. Morphology of insect pollinators found in South Sumatra, Indonesia. A. *Apis cerana*, B. *Apis dorsata*, C. *Apis mellifera*, D. *Elaeidobius kamerunicus*, E. *Elaeidobius* sp. A, F. *Elaeidobius* sp. B, G. *Elaeidobius* sp. C, H. *Elaeidobius* sp. D, I. *Heterotrigona itama*, J. *Saula japonica*, K. *Stratiomys potamida*, L. *Zyginidia* sp., M. Formicidae (unknown species)

Table 2. Abundance of insect pollinators found on male flowers in some sub-districts in South Sumatra, Indonesia

Species	Abundance (individuals/5 spikelets)									P-value
	Banyuasin III	Benakat	Indralaya Utara	Lahat	Lembak	Lempuing Jaya	Sembawa	Sungai Lilin	Teluk Gelam	
<i>Apis cerana</i> Fabricius, 1793	0.00b	0.00b	0.92b	0.00b	56.33a	0.00b	0.00b	0.00b	0.58b	0.03*
<i>Apis dorsata</i> Fabricius, 1793	0.00	0.00	0.00	1.75	0.58	0.92	1.00	1.00	0.58	0.55 ^{ns}
<i>Apis mellifera</i> Linnaeus, 1758	1.83	0.25	0.83	98.75	26.17	0.00	2.00	0.00	20.13	0.53 ^{ns}
<i>Elaeidobius kamerunicus</i> (Faust, 1898) Haran, Beaudoin-Ollivier, Benoit & Kuschel, 2020	206.75bc	203.29bc	194.17bc	575.79a	530.92ab	682.04a	110.00c	195.42bc	705.63a	0.01*
<i>Elaeidobius</i> sp. A	339.96cd	781.46a	386.67bcd	758.50ab	301.63cd	376.42cd	106.42cd	630.33d	285.63abc	0.01*
<i>Elaeidobius</i> sp. B	51.79b	581.71a	46.54b	117.21b	32.04b	39.46b	98.25b	86.50b	17.83b	1.61×10 ⁻³ *
<i>Elaeidobius</i> sp. C	138.67c	75.42c	627.29a	358.83abc	516.25ab	338.71abc	191.71c	237.42bc	314.96bc	0.02*
<i>Elaeidobius</i> sp. D	177.75bc	71.75c	90.54c	281.33bc	489.42abc	921.38a	551.33ab	575.08ab	920.42a	1.36×10 ⁻³ *
<i>Heterotrigona itama</i> Cockerell, 1918	1.25b	0.08b	0.00b	0.00b	57.58a	0.00b	0.00b	0.17b	2.75b	0.01*
<i>Saula japonica</i> Gorham, 1874	0.00b	1.00a	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.04*
<i>Stratiomys potamida</i> Meigen, 1822	0.00b	4.42a	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.75b	0.03*
<i>Zyginidia</i> sp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.46 ^{ns}
Formicidae	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.46 ^{ns}

Note: ns: Not Significantly different*; Significantly different; values within a row followed by the same letters were not significantly different at $P < 0.05$ according to Tukey's HSD test

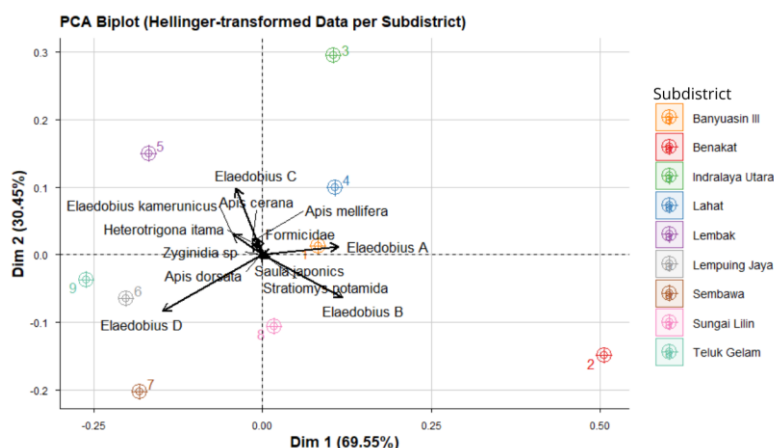


Figure 4. The distribution of insect pollinators in some sub-districts in South Sumatra, Indonesia

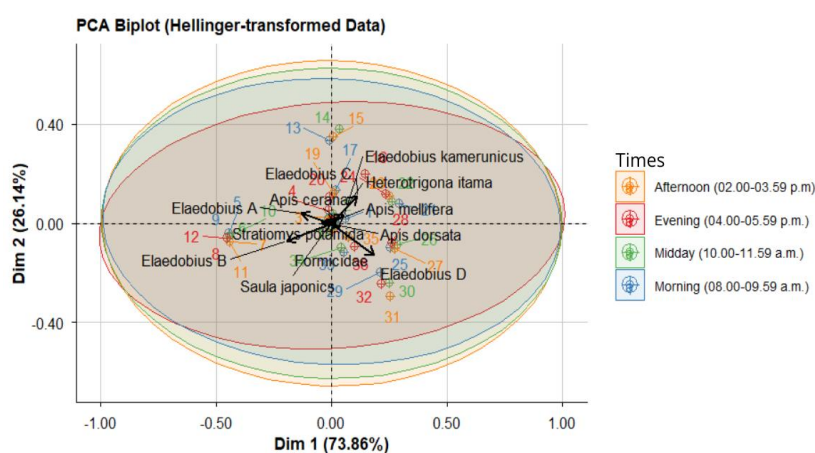


Figure 5. Distribution of insect pollinators in four time intervals observations

Statistical analyses revealed significant differences ($P < 0.05$) in species abundance among locations, including *Elaeidobius* sp. A and C in Banyuasin III, *Elaeidobius* sp. A and *E. kamerunicus* in Benakat, and *Elaeidobius* sp. B in North Indralaya. In contrast, the sting bees, such as *A. cerana*, *A. dorsata*, and *A. mellifera*, were found to be low or absent in most sub-districts. The stingless bee, *H. itama*, however, was found in moderate numbers at several sites, particularly in the Lembak Sub-district, and showed potential as a supplementary pollinator, especially during morning hours. *Apis dorsata* activity in Sungai Lilin also varied significantly over time, with peak activity recorded between 10:00 and 11:59 a.m. Sub-districts, such as Lahat, Benakat, Lempuing Jaya, and Lembak, exhibited high abundances of *E. kamerunicus*, suggesting strong pollination potential, whereas Sembawa and North Indralaya recorded significantly lower pollinator abundances ($P < 0.05$).

Observation time (morning, midday, afternoon, and evening) significantly influenced the species diversity and dominance of pollinating insects on oil palm flowers. The first axis (Dim1=73.86%) and the second axis (Dim2=26.14%) together explained 100% of the variation in pollinator abundance, effectively capturing the overall distribution patterns (Figure 5). During the morning (08.00-09.59 a.m.) represented by the blue symbol, pollinators

exhibited the widest distribution, indicating the highest species diversity. Several bee species, including *A. cerana*, *A. mellifera*, and *H. itama*, were particularly active at this time. The midday period (10:00-11:59 a.m.), represented by the green symbol, also supported high diversity, with species such as *S. japonicus*, *S. potamida*, and Formicidae (unknown species) showing stronger associations, suggesting that pollination activity remained intensive but more selective than in the morning. In the afternoon (2:00-3:59 p.m.), represented by the orange, pollinator activity was dominated by *Elaeidobius* species (*E. kamerunicus*, *Elaeidobius* sp. A-D), reflecting a shift toward specialist dominance. Meanwhile, in the evening (4:00-5:59 p.m.), represented by the red triangle, the distribution narrowed considerably, with activity largely restricted to *A. dorsata*, indicating a sharp decline in overall pollination activity. Overall, the PCA revealed clear temporal variation in pollinator dynamics: the highest diversity occurred in the morning and midday, specialist dominance emerged in the afternoon, and activity dropped markedly in the evening. These findings provide valuable insight into pollinator ecology and highlight the importance of morning to midday periods as potential window for successful oil palm pollination.

Table 3. Abundance of insect pollinators found on male flowers during four observation periods

Location (sub-district)	Abundance (individuals/5 spikelets)	8:00-9:59 a.m.	10:00-11:59 a.m.	2:00-3:59 p.m.	4:00-5:59 p.m.	P-value
Banyuasin III	<i>Apis cerana</i>	0.00	0.00	0.00	0.00	-
	<i>Apis dorsata</i>	0.00	0.00	0.00	0.00	-
	<i>Apis mellifera</i>	0.67	1.08	0.08	0.00	0.10 ^{ns}
	<i>Elaeidobius kamerunicus</i>	41.17	63.75	57.42	45.42	0.07 ^{ns}
	<i>Elaeidobius</i> sp. A	59.33c	103.46a	97.08ab	76.42bc	0.01*
	<i>Elaeidobius</i> sp. B	7.29	16.67	14.29	14.00	0.06 ^{ns}
	<i>Elaeidobius</i> sp. C	25.17b	43.00a	35.67ab	35.25ab	0.02*
	<i>Elaeidobius</i> sp. D	38.79	53.17	50.38	35.50	0.69 ^{ns}
	<i>Heterotrigona itama</i>	0.33	0.92	0.00	0.00	0.18 ^{ns}
	<i>Saula japonica</i>	0.00	0.00	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	0.00	0.00	-
	Formicidae	0.00	0.00	0.00	0.00	-
Benakat	<i>Apis cerana</i>	0.00	0.00	0.00	0.00	-
	<i>Apis dorsata</i>	0.00	0.00	0.00	0.00	-
	<i>Apis mellifera</i>	0.00	0.25	0.00	0.00	0.44 ^{ns}
	<i>Elaeidobius kamerunicus</i>	73.04a	55.38b	38.67c	36.21c	1.47 x 10 ^{-3*}
	<i>Elaeidobius</i> sp. A	246.08a	229.46ab	160.92bc	145.00c	0.04*
	<i>Elaeidobius</i> sp. B	174.63	154.58	128.21	124.29	0.20 ^{ns}
	<i>Elaeidobius</i> sp. C	22.92	20.25	15.92	16.33	0.43 ^{ns}
	<i>Elaeidobius</i> sp. D	19.75	21.00	17.83	13.17	0.84 ^{ns}
	<i>Heterotrigona itama</i>	0.08	0.00	0.00	0.00	0.44 ^{ns}
	<i>Saula japonica</i>	1.00	0.00	0.00	0.00	0.43 ^{ns}
	<i>Stratiomys potamida</i>	2.00	1.92	0.50	0.00	0.28 ^{ns}
	<i>Zyginidia</i> sp.	0.00	0.00	0.00	0.00	-
	Formicidae	0.00	0.00	0.00	0.00	-
Indralaya Utara	<i>Apis cerana</i>	0.42	0.25	0.08	0.17	0.43 ^{ns}
	<i>Apis dorsata</i>	0.00	0.00	0.00	0.00	-
	<i>Apis mellifera</i>	0.50	0.17	0.17	0.00	0.28 ^{ns}
	<i>Elaeidobius kamerunicus</i>	53.08	53.75	44.46	42.88	0.23 ^{ns}
	<i>Elaeidobius</i> sp. A	108.67	105.58	89.96	82.46	0.10 ^{ns}
	<i>Elaeidobius</i> sp. B	18.04a	10.38ab	10.50ab	7.63b	0.01*
	<i>Elaeidobius</i> sp. C	165.88	191.71	134.58	135.13	0.12 ^{ns}
	<i>Elaeidobius</i> sp. D	14.92	12.88	11.92	50.83	0.48 ^{ns}
	<i>Heterotrigona itama</i>	0.00	0.00	0.00	0.00	-
	<i>Saula japonica</i>	0.00	0.00	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	0.00	0.00	-
	Formicidae	0.00	0.00	0.00	0.00	-
Lahat	<i>Apis cerana</i>	0.00	0.00	0.00	0.00	-
	<i>Apis dorsata</i>	1.75	0.00	0.00	0.00	0.44 ^{ns}
	<i>Apis mellifera</i>	0.00	0.00	0.00	0.00	-
	<i>Elaeidobius kamerunicus</i>	157.04	132.96	126.96	140.96	0.71 ^{ns}
	<i>Elaeidobius</i> sp. A	237.21	189.50	212.67	214.50	0.42 ^{ns}
	<i>Elaeidobius</i> sp. B	11.46	36.83	16.33	21.46	0.55 ^{ns}
	<i>Elaeidobius</i> sp. C	90.63	87.83	93.13	87.13	0.99 ^{ns}
	<i>Elaeidobius</i> sp. D	76.54	107.21	74.29	75.79	0.73 ^{ns}
	<i>Heterotrigona itama</i>	0.00	0.00	0.00	0.00	-
	<i>Saula japonica</i>	0.00	0.00	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	0.00	0.00	-
	Formicidae	0.00	0.00	0.00	0.00	-
Lembak	<i>Apis cerana</i>	21.83	22.67	9.25	2.58	0.11 ^{ns}
	<i>Apis dorsata</i>	0.33	0.25	0.00	0.00	0.43 ^{ns}
	<i>Apis mellifera</i>	7.58	10.83	5.75	2.00	0.30 ^{ns}
	<i>Elaeidobius kamerunicus</i>	177.00	161.63	95.04	97.25	0.05 ^{ns}
	<i>Elaeidobius</i> sp. A	87.08	84.00	71.71	58.83	0.75 ^{ns}
	<i>Elaeidobius</i> sp. B	11.00	8.50	7.00	5.54	0.08 ^{ns}
	<i>Elaeidobius</i> sp. C	178.92	125.46	120.21	91.67	0.12 ^{ns}
	<i>Elaeidobius</i> sp. D	181.54	135.42	99.46	73.00	0.07 ^{ns}
	<i>Heterotrigona itama</i>	25.08	21.25	8.58	2.67	0.05 ^{ns}

	<i>Saula japonica</i>	0.00	0.00	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	0.00	0.00	-
	Formicidae	1.00	0.00	0.00	0.00	0.43 ^{ns}
Lempuing Jaya	<i>Apis cerana</i>	0.00	0.00	0.00	0.00	-
	<i>Apis dorsata</i>	0.08	0.00	0.08	0.75	-
	<i>Apis mellifera</i>	0.00	0.00	0.00	0.00	-
	<i>Elaeidobius kamerunicus</i>	174.00ab	153.21b	158.63ab	196.21a	0.03*
	<i>Elaeidobius</i> A	95.58	89.29	94.25	97.29	0.82 ^{ns}
	<i>Elaeidobius</i> B	12.33	6.42	9.83	10.88	0.14 ^{ns}
	<i>Elaeidobius</i> C	82.04	82.33	85.67	88.67	0.91 ^{ns}
	<i>Elaeidobius</i> D	230.88	220.67	239.75	230.08	0.97 ^{ns}
	<i>Heterotrigona itama</i>	0.00	0.00	0.00	0.00	-
	<i>Saula japonica</i>	0.00	0.00	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	0.00	0.00	-
	Formicidae	0.00	0.00	0.00	0.00	-
Sembawa	<i>Apis cerana</i>	0.00	0.00	0.00	0.00	-
	<i>Apis dorsata</i>	0.50	0.50	0.00	0.00	0.36 ^{ns}
	<i>Apis mellifera</i>	0.50	1.50	0.00	0.00	0.13 ^{ns}
	<i>Elaeidobius kamerunicus</i>	27.58	31.25	22.75	28.42	0.21 ^{ns}
	<i>Elaeidobius</i> sp. A	23.50	31.38	24.04	27.50	0.68 ^{ns}
	<i>Elaeidobius</i> sp. B	25.13	25.33	22.04	25.75	0.62 ^{ns}
	<i>Elaeidobius</i> sp. C	49.67	56.13	40.79	45.13	0.16 ^{ns}
	<i>Elaeidobius</i> sp. D	106.21	163.50	150.92	130.71	0.98 ^{ns}
	<i>Heterotrigona itama</i>	0.00	0.00	0.00	0.00	-
	<i>Saula japonica</i>	0.00	0.00	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	0.00	0.00	-
	Formicidae	0.00	0.00	0.00	0.00	-
Sungai Lilin	<i>Apis cerana</i>	0.00	0.00	0.00	0.00	-
	<i>Apis dorsata</i>	0.33ab	0.67a	0.00b	0.00b	0.03*
	<i>Apis mellifera</i>	0.00	0.00	0.00	0.00	-
	<i>Elaeidobius kamerunicus</i>	50.92	50.67	42.42	51.42	0.81 ^{ns}
	<i>Elaeidobius</i> sp. A	144.25	162.50	157.42	166.17	0.53 ^{ns}
	<i>Elaeidobius</i> sp. B	29.00	24.50	16.17	16.83	0.41 ^{ns}
	<i>Elaeidobius</i> sp. C	54.50	53.25	65.17	64.50	0.44 ^{ns}
	<i>Elaeidobius</i> sp. D	143.33	136.42	129.08	166.25	0.69 ^{ns}
	<i>Heterotrigona itama</i>	0.17	0.00	0.00	0.00	0.08 ^{ns}
	<i>Saula japonica</i>	0.00	0.00	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	0.00	0.00	-
	Formicidae	0.00	0.00	0.00	0.00	-
Teluk Gelam	<i>Apis cerana</i>	0.17	0.42	0.00	0.00	0.47 ^{ns}
	<i>Apis dorsata</i>	0.33	0.25	0.00	0.00	0.44 ^{ns}
	<i>Apis mellifera</i>	0.00	0.00	0.00	0.00	-
	<i>Elaeidobius kamerunicus</i>	210.54	175.79	111.96	202.58	0.09 ^{ns}
	<i>Elaeidobius</i> sp. A	113.38	64.92	52.38	79.46	0.24 ^{ns}
	<i>Elaeidobius</i> sp. B	5.75	3.38	4.25	4.58	0.54 ^{ns}
	<i>Elaeidobius</i> sp. C	55.08	45.17	30.75	57.08	0.34 ^{ns}
	<i>Elaeidobius</i> sp. D	281.83	278.42	170.67	316.63	0.41 ^{ns}
	<i>Heterotrigona itama</i>	1.25	1.50	0.00	0.00	0.09 ^{ns}
	<i>Saula japonica</i>	0.00	0.00	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.50	0.25	0.00	0.25	0.27 ^{ns}
	Formicidae	0.00	0.00	0.00	0.00	-

Note: ns: Not Significantly different, *: Significantly different; values within a row followed by the same letters were not significantly different at $P < 0.05$ according to Tukey's HSD test

The abundance of insect pollinators varied significantly across subdistricts and observation times. Significant differences ($P < 0.05$) were detected in Banyuasin III, Benakat, Lempuing Jaya, and Sungai Lilin, with the highest number of individuals recorded during the morning period (8:00-9:59 a.m. and 10:00-11:59 a.m.) (Table 3). Overall, observation time had a significant effect on pollinator abundance, with the highest value recorded between 8:00-9:59 a.m. (4,259 individuals) and the lowest between 4:00-5:59 p.m. (3,478 individuals) ($P = 0.01$). The

diversity index (H') showed significant variations in the Lahat sub-district ($P = 0.02$), where the highest species diversity occurred between 10:00-11:59 a.m. (Table 4). The evenness index (E) differed significantly only in Lahat ($P = 0.03$), while no significant differences were observed in other sub-districts. In contrast, the dominance index (D) did not differ significantly across observation periods or locations ($P > 0.05$), suggesting that no single species consistently dominated the pollinator community throughout the study areas.

Table 4. Community characteristics of insect pollinators found on male flowers during four observation periods

Location (sub-district)	Community characteristics	8:00-9:59 a.m.	10:00-11:59 a.m.	2:00-3:59 p.m.	4:00-5:59 p.m.	P-value
Banyuasin III	Abundance (individuals)	173c	282a	255ab	207bc	$8.11 \times 10^{-3*}$
	Biodiversity index (H')	1.74	1.75	1.74	1.80	0.33 ^{ns}
	Evenness index (E)	0.70	0.71	0.70	0.73	0.31 ^{ns}
	Dominance index (D)	0.36	0.35	0.40	0.35	0.67 ^{ns}
Benakat	Abundance (individual)	540a	483a	362b	335b	0.01*
	Biodiversity index (H')	1.49	1.46	1.48	1.48	0.81 ^{ns}
	Evenness index (E)	0.60	0.59	0.60	0.59	0.84 ^{ns}
	Dominance index (D)	0.46	0.47	0.45	0.44	0.60 ^{ns}
Indralaya Utara	Abundance (individuals)	362	375	292	319	0.31 ^{ns}
	Biodiversity index (H')	1.49	1.48	1.54	1.53	0.73 ^{ns}
	Evenness index (E)	0.60	0.59	0.62	0.62	0.72 ^{ns}
	Dominance index (D)	0.46	0.50	0.47	1.31	0.13 ^{ns}
Lahat	Abundance (individual)	575	554	523	540	0.81 ^{ns}
	Biodiversity index (H')	1.61b	1.74a	1.69ab	1.68ab	0.02*
	Evenness index (E)	0.65b	0.70a	0.68ab	0.68ab	0.03*
	Dominance index (D)	0.42	0.33	0.39	0.39	0.07 ^{ns}
Lembak	Abundance (individuals)	691a	570ab	417b	334b	0.01*
	Biodiversity index (H')	1.79	1.80	1.76	1.72	0.47 ^{ns}
	Evenness index (E)	0.72	0.72	0.71	0.69	0.46 ^{ns}
	Dominance index (D)	0.32	0.35	0.35	0.31	0.71 ^{ns}
Lempuing Jaya	Abundance (individual)	595ab	552b	588ab	624a	0.03*
	Biodiversity index (H')	1.64	1.59	1.64	1.61	0.32 ^{ns}
	Evenness index (E)	0.66	0.64	0.66	0.65	0.35 ^{ns}
	Dominance index (D)	0.40	0.43	0.42	0.39	0.25 ^{ns}
Sembawa	Abundance (individuals)	233	310	261	258	0.09 ^{ns}
	Biodiversity index (H')	1.71	1.64	1.60	1.72	0.21 ^{ns}
	Evenness index (E)	0.69	0.66	0.64	0.69	0.23 ^{ns}
	Dominance index (D)	0.47	0.50	0.53	0.46	0.56 ^{ns}
Sungai Lilin	Abundance (individuals)	423	428	410	465	0.61 ^{ns}
	Biodiversity index (H')	1.71	1.67	1.66	1.67	0.50 ^{ns}
	Evenness index (E)	0.69	0.67	0.67	0.67	0.51 ^{ns}
	Dominance index (D)	0.42	0.46	0.45	0.42	0.41 ^{ns}
Teluk Gelam	Abundance (individuals)	669a	570a	370b	661a	0.01*
	Biodiversity index (H')	1.39	1.26	1.33	1.38	0.29 ^{ns}
	Evenness index (E)	0.56	0.51	0.53	0.56	0.31 ^{ns}
	Dominance index (D)	0.54	0.63	0.57	1.06	0.39 ^{ns}
Total	Abundance (individuals)	4259a	4124ab	3478c	3741bc	0.01*
	Biodiversity index (H')	1.71	1.73	1.74	1.73	0.87 ^{ns}
	Evenness index (E)	0.69	0.70	0.70	0.70	0.86 ^{ns}
	Dominance index (D)	0.26	0.27	0.26	0.23	0.47 ^{ns}

Note: ns: Not Significantly different, *: Significantly different; values within a row followed by the same letters were not significantly different at $P < 0.05$ according to Tukey's HSD test

The abundance of insect pollinators found on male and female flowers

Female and male flowers exhibited distinct dominant pollinator communities. In the biplot (PC1=100% and PC2=0%), female flowers (orange) were positioned in the upper right, while male flowers (gray) clustered in the lower left (Figure 6). Certain species, including *A. mellifera*, *A. dorsata*, and *H. itama*, were more strongly associated with female flowers, whereas *Zyginidia* sp. was closely linked to male flowers. In contrast, members of the genus *Elaeidobius* (*E. kamerunicus* and *Elaeidobius* sp. A–D) occupied a central position, reflecting their consistent association with both flower types, albeit with diffuse contributions. Overall, the biplot revealed clear differences in pollinator preference and dominance: female flowers were more frequently visited by bees (*Apis* spp. and *H. itama*), whereas male flowers were more closely associated with non-bee insects such as *Zyginidia* sp. These findings confirm that pollinator species diversity and abundance differed between male and female flowers.

Elaeidobius kamerunicus, *Elaeidobius* sp. A, and *Elaeidobius* sp. D were the most abundant pollinators, particularly in the Benakat, Lahat, Lempuing Jaya, and Teluk Gelam sub-districts. *Elaeidobius* sp. B and C were also relatively abundant, though their distribution varied more across Sub-districts. Other pollinators, including *A. cerana*, *A. dorsata*, *A. mellifera*, and *H. itama*, were scarce in most areas. Non-*Elaeidobius* pollinators such as *S. japonica*, *S. potamide*, *Zyginidia* sp., and Formicidae (unknown sp.) were detected infrequently in all sub-districts. Pollinators were generally more abundant on male flowers than on female flowers. In particular, *E. kamerunicus*, *Elaeidobius* sp. A, and *Elaeidobius* sp. D dominated male flowers across all sub-districts. Although female flowers supported lower overall pollinator abundance, their species dominance pattern largely

mirrored that of male flowers. Non-*Elaeidobius* pollinators were very rare in both flower types (Figure 7).

Insect pollinators from the genus *Elaeidobius* dominated the oil palm pollinator communities across the surveyed sub-districts, particularly *E. kamerunicus*, *Elaeidobius* sp. A, *Elaeidobius* sp. B, *Elaeidobius* sp. C, and *Elaeidobius* sp. D. The abundance of pollinators was consistently higher on male flowers than on female flowers, with statistically significant differences observed in almost all observation sites (Table 5). Other pollinating species, such as *A. cerana*, *A. dorsata*, and *A. mellifera*, as well as *H. itama*, *S. japonica*, and several other insects, were found in very low numbers or were absent in most locations. Some *Elaeidobius* species, such as *Elaeidobius* sp. B and *Elaeidobius* sp. C showed no significant differences in male and female flower abundance ($P > 0.5$) at several locations, including Banyuasin III, Benakat, Lahat, Lembak, Lempuing Jaya, and Sembawa. In contrast, significant differences were detected between male and female flowers at Sungai Lilin ($P < 0.05$).

Discussion

A total of 13 insect species from the orders Coleoptera, Hymenoptera, and Hemiptera were successfully discovered from oil palm plantations in the lowlands to the middle of South Sumatra, with *E. kamerunicus* and *Elaeidobius* spp. dominating, particularly in the Teluk Gelam Sub-district. This finding demonstrated that *E. kamerunicus* and *Elaeidobius* spp. were not only dominant in the lowlands but also abundant up to an altitude of 167 m above sea level, contradicting the previously held belief that *E. kamerunicus* and *Elaeidobius* spp. are only potential in the lowlands. The findings of this study did not detect species from the orders Lepidoptera and Diptera, as reported by Popkin et al. (2024).

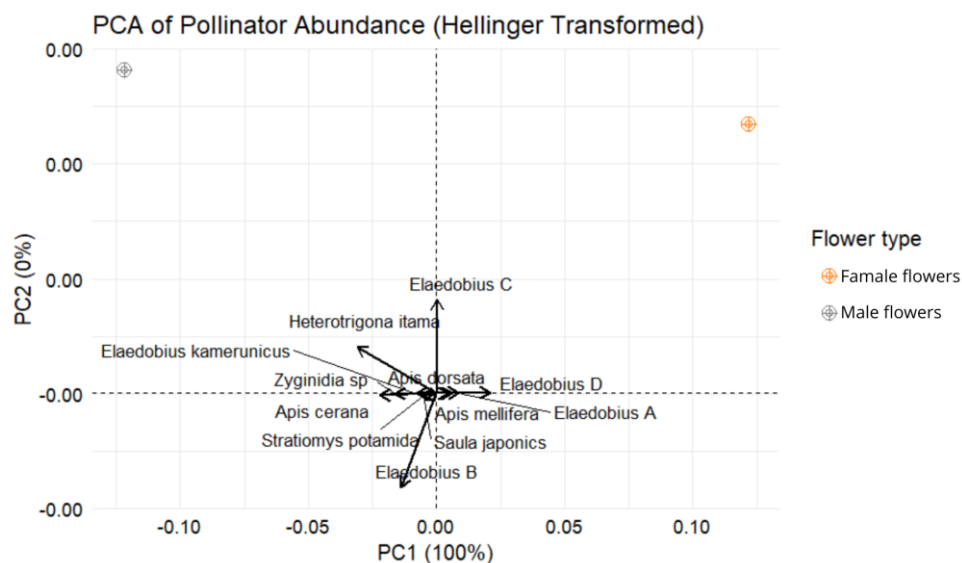


Figure 6. Distribution of insect pollinators on male and female flowers

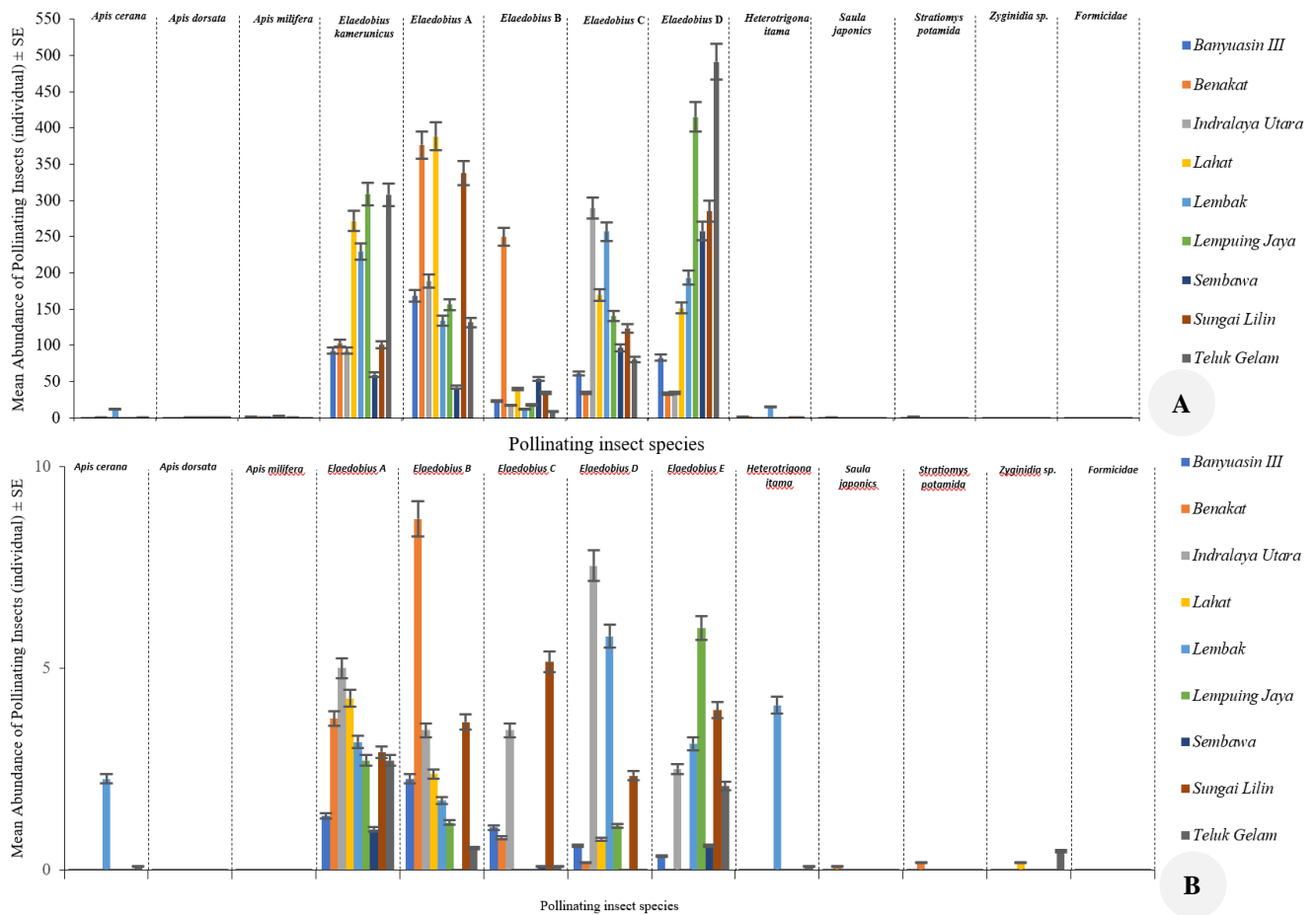


Figure 7. Abundance of insect pollinators found on: A. Male and B. Female flowers

The highest abundance of insects caught in baited flower traps belonged to *E. kamerunicus*, followed by Coleoptera, Diptera, and Lepidoptera. This demonstrated the important role of Coleopterans in oil palm pollination (Santi and Wirianata 2024). The dominance of *Elaedobius* spp. is supported by favorable environmental conditions, such as an effective irrigation system, oil palm age of around six to seven years, the presence of more than six species of refugia plants, and extensive areas of anthesizing male and female inflorescences, approximately around 500 hectares in Lahat and 133 hectares in Lempuing Jaya. The number of beetles was significantly correlated with the abundance of blooming female flowers, and beetle populations differed significantly between six- and eight-year-old plantations (Daud and Ghani 2016). Refugia plants provide food and shelter for pollinators (Amanina et al. 2025; Nelly et al. 2020). Moreover, abiotic factors such as temperature, humidity, wind velocity, and light intensity significantly affect the biology and ecology of *E. kamerunicus* (Rozziansha et al. 2023). The abundance of

pollinators is affected by both plant and landscape variables, though the impact differs based on the type of pollinator and the degree of aggregation (Brandt et al. 2017). This finding supports Rizali et al. (2019) who reported that while plant age and flower type do not affect pollinator abundance and richness, they do influence the species composition. This suggests that a combination of biotic and abiotic factors must be considered when managing pollinator habitats in oil palm agricultural landscapes. Swaray et al. (2025) reported that long-term pollination services may be threatened by factors such as high rainfall and temperature, chemical use, and the presence of natural enemies, all of which can contribute to the decline of *E. kamerunicus* populations. This is consistent with the findings of Permana et al. (2021), who stated that the success of *E. kamerunicus* pollination is influenced by weather, oil palm varieties, soil type, pollen quality and quantity, as well as pressures from parasitic nematodes, predators, insecticide use, beetle endogamy, and plantation distance from natural forest.

Table 5. The abundance of insect pollinators found on female and male flowers

Location (sub-district)	Abundance	Male flowers (individuals/5 spikelets)	Female flowers (individuals/5 bunches)	P-value
Banyuasin III	<i>Apis cerana</i>	0.00	0.00	-
	<i>Apis dorsata</i>	0.00	0.00	-
	<i>Apis mellifera</i>	1.83	0.00	0.20 ^{ns}
	<i>Elaeidobius kamerunicus</i>	92.88a	1.33b	4.67x10 ^{-3*}
	<i>Elaeidobius</i> sp. A	168.42a	2.25b	0.01 [*]
	<i>Elaeidobius</i> sp. B	22.79	1.04	0.08 ^{ns}
	<i>Elaeidobius</i> sp. C	61.33a	0.58b	1.11x10 ^{-3*}
	<i>Elaeidobius</i> sp. D	83.21a	0.33b	7.05x10 ^{-3*}
	<i>Heterotrigona itama</i>	1.25	0.00	0.28 ^{ns}
	<i>Saula japonica</i>	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	-
	Formicidae	0.00	0.00	-
Benakat	<i>Apis cerana</i>	0.00	0.00	-
	<i>Apis dorsata</i>	0.00	0.00	-
	<i>Apis mellifera</i>	0.08	0.00	0.39 ^{ns}
	<i>Elaeidobius kamerunicus</i>	103.17a	3.75b	0.02 [*]
	<i>Elaeidobius</i> sp. A	376.54a	8.71b	0.03 [*]
	<i>Elaeidobius</i> sp. B	249.42	0.79	0.07 ^{ns}
	<i>Elaeidobius</i> sp. C	34.58	0.17	0.39 ^{ns}
	<i>Elaeidobius</i> sp. D	33.42	0.00	0.39 ^{ns}
	<i>Heterotrigona itama</i>	0.08	0.00	0.39 ^{ns}
	<i>Saula japonica</i>	0.25	0.08	0.39 ^{ns}
	<i>Stratiomys potamida</i>	1.75	0.17	0.22 ^{ns}
	<i>Zyginidia</i> sp.	0.00	0.00	-
	Formicidae	0.00	0.00	-
Indralaya Utara	<i>Apis cerana</i>	0.92	0.00	0.25 ^{ns}
	<i>Apis dorsata</i>	0.00	0.00	-
	<i>Apis mellifera</i>	0.83	0.00	0.33 ^{ns}
	<i>Elaeidobius kamerunicus</i>	92.83a	5.00b	0.02 [*]
	<i>Elaeidobius</i> sp. A	188.58a	3.46b	0.02 [*]
	<i>Elaeidobius</i> sp. B	17.17a	3.46b	0.03 [*]
	<i>Elaeidobius</i> sp. C	289.29a	7.54b	6.17x10 ⁻⁴
	<i>Elaeidobius</i> sp. D	34.21	2.50	0.14 ^{ns}
	<i>Heterotrigona itama</i>	0.00	0.00	-
	<i>Saula japonica</i>	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	-
	Formicidae	0.92	0.00	-
Lahat	<i>Apis cerana</i>	0.00	0.00	-
	<i>Apis dorsata</i>	0.58	0.00	0.58 ^{ns}
	<i>Apis mellifera</i>	0.00	0.00	-
	<i>Elaeidobius kamerunicus</i>	271.63a	4.25b	0.01 [*]
	<i>Elaeidobius</i> sp. A	388.13a	2.38b	0.01 [*]
	<i>Elaeidobius</i> sp. B	39.79a	0.00b	0.02 [*]
	<i>Elaeidobius</i> sp. C	169.46	0.75	0.06 ^{ns}
	<i>Elaeidobius</i> sp. D	151.75a	0.00b	0.04 [*]
	<i>Heterotrigona itama</i>	0.00	0.00	-
	<i>Saula japonica</i>	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.17	0.39 ^{ns}
	Formicidae	0.00	0.00	-
Lembak	<i>Apis cerana</i>	12.17	2.25	0.18 ^{ns}
	<i>Apis dorsata</i>	1.17	0.00	0.18 ^{ns}
	<i>Apis mellifera</i>	2.83	0.00	0.11 ^{ns}
	<i>Elaeidobius kamerunicus</i>	229.33a	3.17b	0.01 [*]
	<i>Elaeidobius</i> sp. A	133.92a	1.71b	3.49x10 ⁻⁶
	<i>Elaeidobius</i> sp. B	12.42	0.00	0.09 ^{ns}
	<i>Elaeidobius</i> sp. C	256.88a	5.79b	0.01 [*]
	<i>Elaeidobius</i> sp. D	193.17a	3.13b	3.58 x10 ⁻³
	<i>Heterotrigona itama</i>	15.50	4.08	0.14 ^{ns}
	<i>Saula japonica</i>	0.00	0.00	-

	<i>Stratiomys potamida</i>	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	-
	Formicidae	0.00	0.00	-
Lempuing Jaya	<i>Apis cerana</i>	0.00	0.00	-
	<i>Apis dorsata</i>	0.42	0.00	0.75 ^{ns}
	<i>Apis mellifera</i>	0.00	0.00	-
	<i>Elaeidobius kamerunicus</i>	308.79a	2.71b	9.35 x10 ⁻³
	<i>Elaeidobius</i> sp. A	156.17a	1.17b	0.04 [*]
	<i>Elaeidobius</i> sp. B	17.63a	0.00b	4.48 x10 ⁻³
	<i>Elaeidobius</i> sp. C	140.42	1.08	0.11 ^{ns}
	<i>Elaeidobius</i> sp. D	415.13a	6.00b	0.01 [*]
	<i>Heterotrigona itama</i>	0.00	0.00	-
	<i>Saula japonica</i>	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	-
	Formicidae	0.00	0.00	-
Sembawa	<i>Apis cerana</i>	0.00	0.00	-
	<i>Apis dorsata</i>	0.33	0.00	0.49 ^{ns}
	<i>Apis mellifera</i>	0.67	0.00	0.20 ^{ns}
	<i>Elaeidobius kamerunicus</i>	59.67a	1.00b	0.04 [*]
	<i>Elaeidobius</i> sp. A	42.54a	0.00b	0.02 [*]
	<i>Elaeidobius</i> sp. B	54.21a	0.08b	0.02 [*]
	<i>Elaeidobius</i> sp. C	96.29a	0.00b	0.01 [*]
	<i>Elaeidobius</i> sp. D	257.38	0.58	c0.07 ^{ns}
	<i>Heterotrigona itama</i>	0.00	0.00	-
	<i>Saula japonica</i>	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	-
	Formicidae	0.00	0.00	-
Sungai Lilin	<i>Apis cerana</i>	0.00	0.00	-
	<i>Apis dorsata</i>	1.00	0.00	0.14 ^{ns}
	<i>Apis mellifera</i>	0.00	0.00	-
	<i>Elaeidobius kamerunicus</i>	100.63a	2.92b	5.56 x10 ⁻³
	<i>Elaeidobius</i> sp. A	337.63a	3.67b	3.97 x10 ⁻³
	<i>Elaeidobius</i> sp. B	34.63a	5.17b	1.85 x10 ⁻³
	<i>Elaeidobius</i> sp. C	123.54a	2.33b	0.01 [*]
	<i>Elaeidobius</i> sp. D	284.96a	3.96b	0.01 [*]
	<i>Heterotrigona itama</i>	0.17	0.00	0.18 ^{ns}
	<i>Saula japonica</i>	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.00	-
	Formicidae	0.00	0.00	-
Teluk Gelam	<i>Apis cerana</i>	0.33	0.08	0.39 ^{ns}
	<i>Apis dorsata</i>	0.25	0.00	0.39 ^{ns}
	<i>Apis mellifera</i>	0.00	0.00	-
	<i>Elaeidobius kamerunicus</i>	307.79	2.71	0.12 ^{ns}
	<i>Elaeidobius</i> sp. A	131.75	0.54	0.07 ^{ns}
	<i>Elaeidobius</i> sp. B	8.42	0.08	0.32 ^{ns}
	<i>Elaeidobius</i> sp. C	80.46	0.00	0.34 ^{ns}
	<i>Elaeidobius</i> sp. D	491.25a	2.08b	2.23 x10 ⁻³
	<i>Heterotrigona itama</i>	0.83	0.08	0.21 ^{ns}
	<i>Saula japonica</i>	0.00	0.00	-
	<i>Stratiomys potamida</i>	0.00	0.00	-
	<i>Zyginidia</i> sp.	0.00	0.46	0.28 ^{ns}
	Formicidae	0.00	0.00	-

Note: ns: Not Significantly different, *: Significantly different; values within a row followed by the same letters were not significantly different at $P < 0.05$ according to Tukey's HSD test

Bee species from the genus *Apis*, such as *A. cerana* and *A. dorsata*, had a low abundance and were nearly undetectable in some areas. Only *A. cerana* was found in small numbers in North Indralaya and Teluk Gelam, while *A. dorsata* was almost completely absent from all study sites. In contrast, Siregar et al. (2016) found that *A. dorsata* and *Trigona* sp. were the most common pollinating insects in oil palm plantations. Raffiudin et al. (2024) found that, while *A. dorsata* can fly long distances to find pollen sources; its abundance remains low in oil palm plantations, indicating resource limitations in these habitats. In addition, other insects such as *H. itama*, *S. japonica*, *S. potamide*, and *Zyginidia* sp. were found to be in low abundance or absent in most study sites, indicating that they serve as supplementary pollinators but are not dominant. In contrast, *Elaeidobius* consistently emerged as the dominant pollinator in the majority of study sites, while *Apis* and *Zyginidia* sp. were more closely associated with sites that have unique microhabitat conditions. According to Ramadani et al. (2021), the foraging behavior of each stingless bee species is heavily influenced by various environmental factors, such as the supporting vegetation and the diversity of microhabitats surrounding oil palm plantations. In the present study, refugia plants that could support pollinator diversity were limited, restricted to about 5-10 m on either side of the river. According to a study published by the British Ecological Society, a riparian buffer width of 20 to 30 m on each side of the river in oil palm plantation landscapes can create more natural microclimate conditions and significantly increase biodiversity, including insect and pollinator communities (Williamson et al. 2021). Power et al. (2022) revealed that pollinating bees rely on the presence of remaining forest, and higher forest fragmentation supports larger bee populations. These findings underscore the importance of sustainable management of refugia habitats within oil palm plantations. Expanding and maintaining refugia, particularly riparian buffers and forest fragments, is critical to boosting the abundance and diversity of pollinators, especially bees that are essential for sustaining ecosystem functions and long-term crop productivity.

The abundance of oil palm pollinating insects in South Sumatra showed activity patterns that were strongly influenced by the time of observation. Most activity occurred in the morning between 08:00 and 09:59 a.m., with the genus *Elaeidobius* spp. being the most prevalent. During this time, the diversity of pollinating insects reached its peak, including several bee species like *A. cerana*, *A. mellifera*, and *H. itama*, which exhibited increased activity. This finding is consistent with the findings of Koua et al. (2012) and Siregar et al. (2016), who reported peak feeding activity of pollinating insects in the morning (08:00-09:59 a.m.). Statistical analysis also revealed significant differences in several *Elaeidobius* spp. between the Banyuasin III and North Indralaya sites. Furthermore, Auffray et al. (2017) reported that *E. kamerunicus* is active in the morning, whereas *Grasidius hybridus* O'Brien & Beserra, 2004 is active briefly at dusk, using a synchronous visit pattern on male and female flowers as a pollination mutualism strategy. During the day

(10:00-11:59 a.m.), pollination activity remains high, but diversity begins to decline, according to Saravanan et al. (2024), who observed the peak abundance of *E. kamerunicus* around 10:00-11:00 a.m., dominated by female beetles, then gradually decreasing until the afternoon and evening. In the afternoon (2:00-3:59 p.m.), pollination activity is concentrated on specialist species such as *E. kamerunicus* and some *Elaeidobius* morphotypes, indicating pollinator dominance. Activity decreases dramatically in the evening (4:00-5:59 p.m.), with only a few species, such as *A. dorsata*, remaining active in small numbers. Thus, oil palm pollination activity is at its peak from morning to midday, with a significant decrease in the afternoon and evening. Individual pollinator abundance varied significantly across sub-districts, with peak abundance typically occurring between 8:00 and 11:59 a.m. Pollinator diversity and evenness differed significantly only in the Lahat sub-district, particularly between 10:00 and 11:59 a.m., with no significant differences observed in other locations. A stable dominance index without significant differences indicates that no single species dominates the pollinator community across all sub-districts. This reflects a relatively balanced pollinator community, despite differences in individual abundance over time and location.

The abundance of pollinating insects on male and female flowers varied, with each flower having a distinct species preference. In general, *E. kamerunicus*, *Elaeidobius* sp. A, and *Elaeidobius* sp. D was the most prevalent species on both types of flowers, though its abundance was greater on male flowers. This is consistent with previous reports that several species, including *Elaeidobius* spp., *Microporum* sp., *Prosoestus* sp., and *Atheta burgeoni*, were found on both types of flowers (Koua et al. 2012).

This pattern is related to the bioecology of *Elaeidobius*, as studies by Auffray et al. (2017) and Permana et al. (2021) showed that *E. kamerunicus* uses male flowers for breeding and visits female flowers for their scent. In several sub-districts, including Benakat, Lahat, Lempuing Jaya, and Teluk Gelam, *Elaeidobius* species were abundant on male flowers, while their numbers on female flowers were less abundant, with *Elaeidobius* remaining the dominant species. Estragole, a volatile organic compound released by oil palm inflorescences during anthesis, has been shown to play an important role in attracting *E. kamerunicus* to oil palm inflorescences (Aisagbonhi et al. 2004; Fahmi-Halil et al. 2021). This suggests that, while *Elaeidobius* is an important pollinator in both flower types, male flowers are more attractive due to their higher nectar concentration and floral structures better suited to the insect's life cycle. Other pollinators such as *A. cerana*, *A. dorsata*, and *A. mellifera*, as well as the stingless bee *H. itama*, were present in extremely low abundances on both flower types. *Apis mellifera* and *A. dorsata* were more commonly seen with female flowers, while *H. itama* was found in specific locations, such as Lembak, in the morning. This indicates that although these bee species contribute to pollination, their role is minor compared with that of *Elaeidobius*, and their limited occurrence is likely shaped by environmental conditions and resource

availability. Non-*Elaeidobius* species such as *S. japonica*, *S. potamide*, *Zyginidia* sp., and Formicidae were extremely rare, nearly undetectable in most study sites. Their very low abundance suggests that these species make only a marginal contribution to the oil palm pollination process, with minimal ecological impact compared to *Elaeidobius*.

In conclusion, *E. kamerunicus* and other *Elaeidobius* species are the predominant insect pollinators in oil palm production areas of South Sumatra, occurring from the lowlands (7 masl) to the midlands (167 masl). These beetles were recorded on both male and female flowers, but were consistently more abundant on male flowers. Their activity extended throughout the day, with peak abundance observed between 8:00 and 11:59 a.m. Similarly, *A. mellifera* and *A. dorsata* visited both flower types, though their activity was mostly concentrated in the morning to midday period. The potential of these species as pollinators lies in their ability to transfer pollen between male and female flowers. Environmental factors and plantation age influenced pollinator distribution, highlighting the importance of maintaining vegetation diversity and reducing pesticide use to support sustainable pollination. This study was limited to a single sampling period and did not account for seasonal variation or microclimatic effects. Future studies should conduct long-term monitoring across different seasons and integrate molecular and behavioral analyses to better understand pollinator dynamics and their role in sustainable oil palm management.

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