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Biodiversity of Apocrita (Hymenoptera) in Banting Oil Palm Plantations: A Study of Species Richness and Abundance

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ABSTRACT

Hymenoptera is a diverse and large group of insects that is divided into suborder Symphyta and Apocrita, including bees, wasps, ants and sawflies. To date, there has been no study on Apocrita insects inhabiting the oil palm plantations in Banting. The establishment of oil palm plantations can lead to the destruction of natural habitats, potentially affecting both plant and animal biodiversity. Consequently, there are concerns that oil palm cultivation may have negative ecological impacts. The objectives of this study were to determine the diversity and abundance of suborder Apocrita at Oil Palm Plantation, Banting and to compare its diversity and abundance at three different areas, inner (Trap 1), middle (Trap 2) and outer (Trap 3). A Malaise trap was installed at each sampling site, and insects were collected and identified after one month. Biostatistical parameters such as Shannon-Wiener diversity index (H'), evenness index (E'), and Margalef richness index (R') were used to identify abundance, evenness and richness of the family Apocrita. From the results obtained, the most abundant Apocrita found was from Trap 1, with 1767 individuals collected, followed by Trap 2 and Trap 3, with 183 and 2 individuals, respectively. Trap 3 exhibited the highest evenness index, with $E' = 1.000$, signifying a perfectly even distribution where all species were equally abundant in the outer area compared to Trap 1 and Trap 2 with $E' = 0.231$ and $E' = 0.312$. The Margalef richness index (R'), showed the highest value of $R' = 2.006$ in Trap 1, suggesting that the greatest species richness was observed there with 105 morphospecies while for Trap 2 and Trap 3, there were only 16 and 2 morphospecies found. This study suggests that Apocrita abundance is higher in the inner areas of the oil palm plantation compared to the middle and outer areas. This study is important as it provides insights into the potential ecological impacts of oil palm plantations and contributes to the improvement of sustainable agricultural practices. Moreover, certain Apocrita species may benefit agriculture by serving as pollinators and natural enemies of crop pests.

Keywords:

Hymenoptera; Apocrita; oil palm; diversity; abundance

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1. Introduction

Insects are members of the arthropod group, which was one of the largest and most diverse groups of animals, with approximately 3.9 million species dominating tropical rainforests [1]. The order Hymenoptera consists of ants, bees, wasps, and sawflies are among the most numerous and diverse insect orders [2]. Hymenoptera later was divided into two suborders, namely Symphyta and Apocrita [3]. Apocrita members included ants, bees, wasps, and nearly all parasitic hymenopterans [4]. In ecosystems, Apocrita insects were recognized as crucial faunistic elements. By acting as both predators and parasitoids, they contributed to the regulation of various insect populations, helping to maintain ecological balance. A significant relationship between the diversity of insect species and the equilibrium of environmental conditions was observed [5]. Additionally, Apocrita insects were identified as essential pollinators, facilitating the reproductive processes of flowering plants and supporting overall ecosystem health [6]. Flower-visiting insects, such as bees, wasps, and ants, were responsible for pollination, which was considered an essential function in the ecosystem, and these insects made a considerable contribution to the reproductive fitness and conservation of plant populations [7].

Oil palm cultivation was one of the most common agricultural activities in Southeast Asia, resulting in significant changes to natural habitats and increasing pressure on biodiversity [8]. Malaysia began commercial oil palm plantation cultivation in the early 20th century. By that time, Malaysia had become one of the world's leading producers of palm oil, with approximately six million hectares of oil palm plantation found in both Peninsular and East Malaysia. The favourable climate, with abundant sunlight and consistent rainfall, has promoted optimal oil palm growth conditions, allowing Malaysia to be one of the world's leading producers and exporters. However, the reputation of oil palm has suffered due to the negative environmental impacts of its cultivation, particularly in terms of deforestation and the creation of haze [9]. Therefore, it was very important to identify management strategies that could support biodiversity in plantations without exacerbating negative impacts on the environment [8]. A significant amount of disturbance has been caused to the tropical forests because of logging and clearance for agricultural purposes, particularly to produce palm oil, cocoa, grazing, and rubber plantations [10]. Change in sustainable development had an immediate impact on the number and species richness of this insect because they caused disturbances in the oviposition sites, food sources, nesting areas, and breeding sites of many insects, including pollinators [11].

The distribution and abundance of Apocrita in the Banting oil palm plantation have not been explored, leaving unknown species and environmental variations. This study aims to establish a preliminary inventory of insects, especially Apocrita, which have experienced significant biodiversity loss due to deforestation and clear-cutting. Habitat-altering activities, especially for agricultural purposes, have disrupted ecosystems and impacted insect populations. The findings from this study aimed to provide more detailed information about Apocrita insects. It was also aimed to determine the habitat requirements for Apocrita insects to live and reproduce in the area. Furthermore, the findings could demonstrate whether the community's notion that oil palm plantations caused extensive damage to plants and insects was correct. The main objective of this study was to investigate the diversity and abundance of the suborder Apocrita in the Banting Oil Palm Plantation, alongside comparing these factors across three distinct areas within the plantation.

2. Methodology

The study was conducted at an oil palm plantation located in Bukit Perah, Banting, Selangor (2°51'59.9"N 101° 33' 41.3" E). Three different areas, which are the inner, middle and outer part, were selected and used in setting up the malaise traps with coordinates (2.86670° N, 101.56227° E), (2.86647° N, 101.56156° E) and (2.86739° N, 101.56120° E).

The method used in this research involved the collection of samples using Malaise traps (**Figure 1**). Malaise traps can trap many flying insects, including Hymenoptera, as well as various species [12]. Due to their low maintenance requirements, these traps are suitable for extended monitoring periods, capturing both flying insects and ground-dwelling species [13]. The malaise trap is like a large tent made of light material, hung between two poles. At the top of the trap, there was a jar where insects were collected as they moved upward. The trapped insects ended up in the container, making it easier for researchers to collect and study them.



Fig. 1. Malaise trap

One Malaise trap was set up in each area. The distance between Malaise traps was approximately 100 m. The trap was left at the sampling area for a whole month. Hymenopteran specimens found in the container of the trap were sorted based on their respective families. This sorting process relied on examining their morphological and physical characteristics, using a stereoscopic microscope for detailed and accurate analysis. The specimens were then identified to their morphospecies. The Statistical Package for the Social Sciences (SPSS) was used in this study to evaluate the differences between the datasets. A normality test was performed using SPSS to determine whether the data distribution was normal or not. Since the data was not normally distributed, a non-parametric Kruskal-Wallis test was applied to determine if there were statistically significant differences between those traps. The biodiversity indices used in this study were the Shannon-Weiner Diversity Index, Evenness Index, and Margalef Richness Index. Then, ANOVA will be applied to assess the diversity and abundance of suborder Apocrita insects across three distinct areas within the oil palm plantation.

3. Results and Discussion

A total of 1952 individuals of the suborder Apocrita were found in the oil palm plantation in Banting, Selangor, using three Malaise traps placed in different areas within the plantation. These traps were labelled as Trap 1 (inner), Trap 2 (middle) and Trap 3 (outer). There were 17 families found among the individuals resulting in 109 morphospecies recorded based on the differences in their morphology and appearance. The families identified were Formicidae (ants), Scelionidae (scelionid wasps), Ichneumonidae (ichneumon wasps), Braconidae (braconid wasps), Vespidae (wasps, hornets, and yellowjackets), Platygasteridae (platygasterid wasps), Diapriidae (diapriid wasps), Crabronidae (crabronid wasps), Chalcididae (chalcid wasps), Pompilidae (spider wasps), Evaniidae (ensign wasps), Colletidae (plasterer bees or polyester bees), Pteromalidae (pteromalid wasps), Cerocephalidae (chalcid wasps), Sierolomorphidae (sierolomorphid wasps), Cynipidae (gall wasps) and Eulophidae (eulophid wasps).

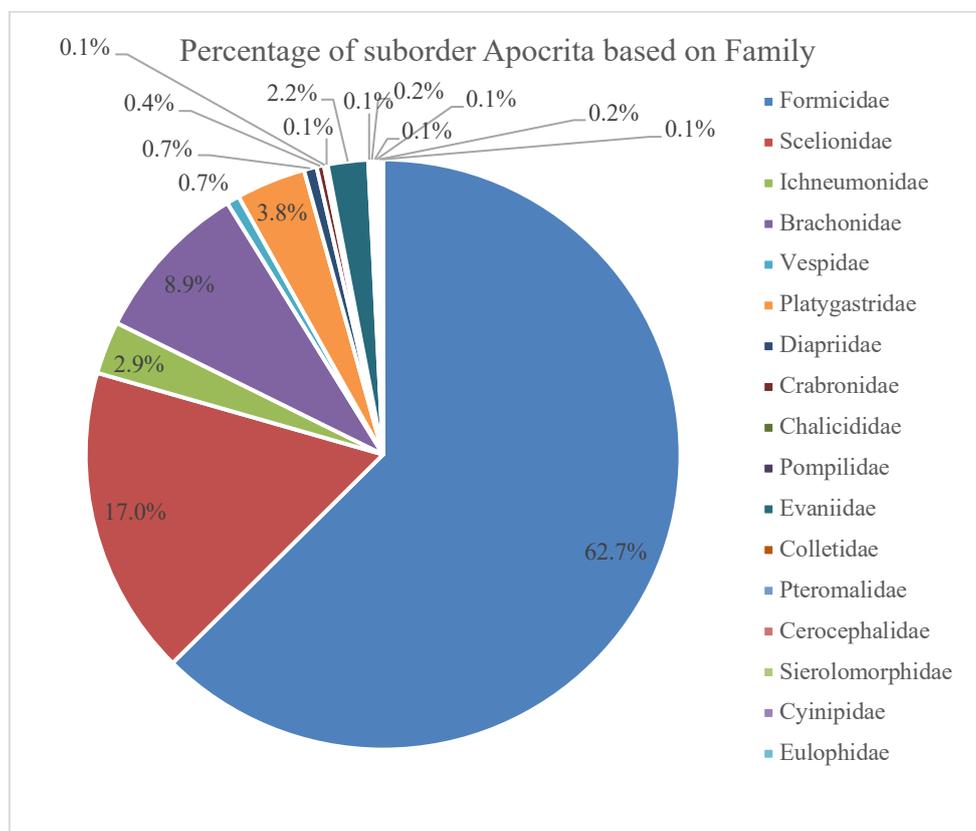


Fig. 2. The percentage of suborder Apocrita collected from Oil Palm Plantation, Banting

3.1 The Number of Apocritan per Family

Based on **Figure 2**, it is shown that the family Formicidae has the highest number of individuals, with 1224 individuals from 28 morphospecies. This was because they are the most well-known hymenopterans that frequently establish colonies and display sociable behavior [14]. Additionally, the widespread distribution, high diversity, and adaptability of ants allow them to be present in all habitats [15]. The advanced age of the oil palm trees in the plantation may also contribute to the high numbers of ants recorded. This was because the diversity index of the ant community tended to be higher in areas with older palm stands, indicating that the equilibrium level of the ant community structure in these locations is higher than in areas with younger palms [16]. Other than

that, ants are the most abundant invertebrates found in the soil, leaf litter, epiphytes, and canopy within the oil palm plantations [17].

Table 1
 Number of individuals

Family	Number of Morphospecies	Trap 1	Trap 2	Trap 3	Total Individual
Formicidae	28	1070 (28)	153 (7)	1 (1)	1224
Scelionidae	10	312 (10)	18 (3)	1 (1)	331
Ichneumonidae	16	54 (13)	3 (3)	0	57
Brachonidae	30	174 (30)	0	0	174
Vespidae	6	14 (6)	0	0	14
Platygastridae	1	68 (1)	7 (1)	0	75
Diapriidae	1	12 (1)	1 (1)	0	13
Crabronidae	5	8 (5)	0	0	8
Chalcididae	1	1 (1)	0	0	1
Pompilidae	1	2 (1)	0	0	2
Evaniidae	2	42 (2)	0	0	42
Colletidae	1	1 (1)	0	0	1
Pteromalidae	2	4 (2)	0	0	4
Cerocephalidae	1	1 (1)	0	0	1
Sierolomorphidae	1	1 (1)	0	0	1
Cynipidae	2	3 (2)	0	0	3
Eulophidae	1	0	1 (1)	0	1
Total Individual		1767	183	2	1952
Percentage		90.5%	9.4%	0.1%	
Total Family	17	16	6	2	
Total Morphospecies	109	105	16	2	

*The value in the bracket is the total number of morphospecies among families of suborder Apocrita at the study site.

3.2 The Abundance of Suborder Apocrita by Traps

According to **Table 1**, the total number of individuals collected at the research locations was 1952. Trap 1 was located in the inner area of the plantation, while Trap 2 was located in the middle area of the plantation and Trap 3 was located in the outer area of the plantation. Based on **Figure 3**, Trap 1 recorded the highest number of individuals, with 1767 representing 90.5% of the total. Trap 2 recorded 183 individuals, accounting for 9.4% of the total, while Trap 3 recorded the lowest number, with only 2 individuals, representing only 0.1% of the total.

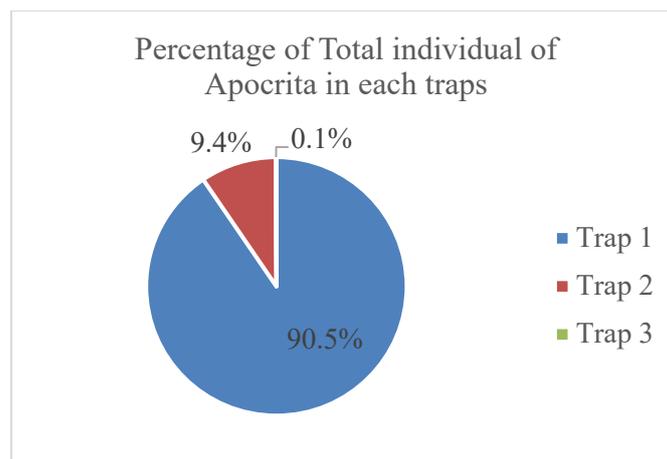


Fig. 3. Percentage of total individual of Apocrita in each trap

In this study, 17 families with 109 morphospecies were found within the suborder Apocrita. Trap 1 recorded the highest number of discovered families, with a total of 16 families and 105 morphospecies. Meanwhile, Trap 2 recorded a total of 6 families and 16 morphospecies and Trap 3 recorded only 2 families and 2 morphospecies. However, not all identified morphospecies are present in each trap.

3.2.1 Abundance of suborder Apocrita in inner trap

Based on **Table 1**, Trap 1 which is located at the inner of the plantation, recorded the highest number of individuals which was a total of 1767 individuals from 16 families and 105 morphospecies where mostly from Formicidae family or ants. Despite being located in the inner area of the oil palm plantation, which is dense with oil palm trees and other vegetation, Trap 1 still receives direct sunlight as it is not shaded by any leaves or trees. The high number of ants may be attributed to the link between temperature and community-level richness across various scales and contexts, indicating that communities will support a greater diversity of ant species as temperatures increase [18]. It was found that one of the most significant factors influencing the high insect count in Trap 1 is the proximity of a nearby ditch. This is because bees and non-parasitic wasps under Hymenoptera order forage for free water which is required for their larvae, nest construction, and thermoregulation [19]. There are some families of bees and non-parasitic wasps present in the inner trap, such as the family Colletidae, which consists of bees, and the families Crabronidae, Vespidae and Pompilidae, which consist of non-parasitic wasps. Other than that, water also constitutes 88–98% of floral nectar, 89–94% of insect honeydew, and 90–95% of insect haemolymph [19].

3.2.2 Abundance of suborder Apocrita in middle trap

Trap 2, located in the middle of the plantation, was the second highest trap, with a total of 183 individuals from 6 families and 16 morphospecies. Like Trap 1, it is predominantly contributed to by the Formicidae family. It was observed that in this trap, there was less leaf litter and vegetation coverage compared to Trap 1, possibly influenced by the location near a motor track area, leading to diminished plant life in that vicinity. Plantations without tree biodiversity enrichment had the lowest ant and parasitoid species richness [20]. Direct sunlight was also received by Trap 2, as no oil palm trees are planted nearby to shade the trap with their leaves. However, since Trap 2 was located in the middle part of the plantation, the vegetation coverage, shaded region and humidity were lower than Trap 1. As a result, sunlight is directly exposed to the plantation soil surface. However, the soil

remains relatively moist due to the lack of vegetation to absorb water from it, unlike in Trap 1. This is because a large amount of soil water will be absorbed if there is a large-scale presence of vegetation, which will form a dry soil layer [21]. It is often assumed that open bare ground and lower humidity are preferred by female bees for nest initiation over vegetative cover because nests are often found in sparsely vegetated areas [22]. This could be one of the factors contributing to the lower number of individuals recorded in Trap 2 compared to Trap 1.

3.2.3 Abundance of suborder Apocrita in outer trap

Trap 3, which is in the outer area of the plantation, recorded the lowest number of individuals, with a total of 2 individuals from 2 families and 2 morphospecies. This means that only one individual was recorded for each family and morphospecies. Trap 3 also received sunlight just like Trap 1 and Trap 2. High temperatures, low humidity, and other environmental and biological conditions are promoted by more sunlight exposure [23]. This trap was situated near the road, which caused significant noise, pollution, and other negative impacts on insects and the environment. Insects' physiology and ethology can be impacted by noise [24]. In addition to this, insects can also be indirectly affected by the combustion gases released through increased traffic volume [25]. Additionally, it was found that asphalt roads and pavements can reach temperatures as high as 60 °C, radiating excess heat back into the environment [26]. This may result in this trap having a higher temperature compared to the other two traps. Rising temperatures will negatively impact species living in thermally variable microhabitats, such as those in the canopy and leaf litter environments [18]. Other than that, the survival, reproduction, and metabolism of bees will be adversely affected by the high temperature and high humidity environment [27].

3.4 Diversity (H'), Evenness (E') and Richness (R') of Suborder Apocrita

The species diversity of the overall data was examined using the Shannon-Wiener diversity index (H'), Evenness index (E'), and Margalef richness index (R'). According to **Table 2**, the highest Shannon-Wiener diversity index value was exhibited by trap 1, with an H' value of 1.305. In contrast, lower diversity indices were observed in traps 2 and 3, with H' values of 0.627 and 0.693, respectively. This indicates that a greater level of species diversity was present in trap 1 compared to the other two traps. This is because the high value of the Shannon-Wiener diversity index reflects high species diversity [28]. However, none of the three traps were considered to have good diversity, as their values were less than 3. This was because a good and high diversity index value is supposed to be in the range of 3 to 5 [29].

Table 2
Diversity indices analysis of Oil Palm Plantation, Banting

Trap	H'	E'	R'
1	1.305	0.231	2.006
2	0.627	0.312	0.960
3	0.693	1	1.443

The greatest evenness index was found in trap 3, with $E' = 1.000$, indicating a perfectly even distribution where all species were equally abundant in the outer area of the oil palm plantation. The Species Evenness Index (E') is categorized as low (< 0.3), moderate (0.3 to 0.6), and high (> 0.6) [30].

Accordingly, Trap 1 exhibits low evenness, Trap 2 demonstrates moderate evenness, and Trap 3 shows high evenness. This indicates that there are dominating families in Trap 1 and Trap 2, which were the family Formicidae in both traps.

The Margalef richness index (R'), which reflects the number of species relative to the sample size, showed the highest value of $R' = 2.006$ in Trap 1, suggesting that the greatest species richness was observed there. This aligns with its high Shannon-Wiener index, indicating a diverse array of species. Trap 2 and Trap 3 have richness index (R') values of 0.960 and 1.443, respectively. However, Trap 1 was still categorized as low species richness. This was because the richness index (R') was categorized as low ($R < 3.5$), moderate ($3.5 < R' < 5$), and high ($R' > 5$) [30].

Normality tests were conducted for family versus trap and morphospecies versus trap. The results indicated that family versus trap was significant, with a P value of 0.000 ($P < 0.05$), while morphospecies versus trap showed non-significance with a P value of 0.962 ($P > 0.05$). Due to the significance of family versus trap, the Kruskal-Wallis test was employed, whereas for morphospecies versus trap, One-way ANOVA was used because it was not significant. Significant insights into the distribution of hymenopteran families in three different oil palm plantation areas were provided by the Kruskal-Wallis test. Differences in abundance and diversity are shown by the results, indicating that the presence and abundance of Hymenopteran families is influenced by the trap environment. To determine which pairs of traps contributed to the significant value, post hoc tests of pairwise comparisons were conducted to reveal significance between traps.

The results shown in **Table 3** indicated that a significant value of $P = 0.000$ was observed for the pair of trap 2 - trap 1, indicating a statistically significant difference between these two pairs in terms of measured parameters like abundances or richness, while $P = 1.000$ were observed for trap 2 - trap 3 and trap 1 - trap 3, indicating that there was no significant difference between family distribution in these traps.

Table 3
Pairwise comparisons of family versus trap

Trap	Pairwise Comparisons of Trap (P Value)
2 - 1	0.000
2 - 3	1.000
1 - 3	1.000

3. Conclusion

Overall, the Formicidae family was the most abundant among the Apocrita suborder, accounting for 62.7% of the total with 1,224 ants captured across three different traps. The second most abundant family was Scelionidae, consisting of parasitoid wasps, which represented 17% of the total with 331 individuals. The third highest count of Apocrita amounted to 174 individuals, representing 8.9% of the total. In contrast, the families Chalcididae, Colletidae, Cerocephalidae, Sierolomorphidae, and Eulophidae each had the lowest representation, with only one individual per family, making up just 0.1% of the total.

The highest number of individuals was recorded at the inner trap, with 1,767 specimens representing 16 families and 105 morphospecies. As expected, Trap 1 (Inner Trap) recorded the highest value for both the Shannon-Wiener diversity index and richness index, which were 1.305 and 2.006, respectively. This high abundance was likely influenced by the trap's proximity to a ditch that provided water and supported dense vegetation, offering ample resources and diverse habitats. Additional contributing factors included exposure to direct sunlight and the presence of leaf litter,

which created favorable conditions for ants and other insects. In contrast, the middle trap recorded a lower count of 183 individuals from 6 families and 16 morphospecies. Both the Shannon-Wiener diversity index and richness index for Trap 2 (middle trap) show the lowest value with 0.627 and 0.960, respectively. This reduced abundance is likely due to its location near a motor track, with limited vegetation growth. Although the area had moist soil and received direct sunlight, these conditions may have been less suitable for some insects, resulting in reduced diversity and numbers. The outer trap recorded the lowest count, with only 2 individuals, each representing a different family and morphospecies. This contributes to a high value in the Species Evenness index. Harsh environmental conditions, including high temperatures, low humidity, and noise pollution from a nearby road likely caused this extremely low number. Despite the presence of puddles and streetlights, which typically attract insects, these unfavourable conditions likely deterred them from the area.

In conclusion, the study highlighted the influence of environmental factors such as water availability, vegetation cover, sunlight, soil moisture, and noise on the abundance and diversity of Apocrita insects in an oil palm plantation. These factors should be understood to aid in the conservation and management of insect biodiversity in agricultural landscapes. This study would be beneficial in the agricultural industry since most of the Apocrita insects could act as pollinating insects and natural predators. In agriculture, effective pollination was critical because high-quality and abundant yields were required.

Several limitations can be identified from this study such as a short sampling period and only morphological identification is being used. As a recommendation, further studies on the suborder Apocrita are still needed, as not many families were found in this study, and various other factors might have influenced the abundance, richness, and evenness of Apocrita insects. Furthermore, longer-term studies over seasons might be needed as it might influence the diversity and abundance of the insects. In the future, it is recommended to employ advanced technology such as molecular tools that can identify insect species more accurately.

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