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The effect of land cover on the foraging behavior and pollen in the honey of the giant bee *Apis dorsata* in Sumatra

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Introduction: *Apis dorsata*, the common bee pollinator in tropical forests, is experiencing a population decrease due to several anthropogenic factors that lead to land cover changes and habitat loss. Land cover changes may alter their resource supply and foraging behavior. Our study aimed to determine foraging behavior and botanical origin using pollen of *A. dorsata* honey in two land cover types: plantation-dominated landscape (PL) in Kampar (Riau) and forest-agriculture-dominated landscape (FL) in Kerinci (Jambi) Sumatra, Indonesia.

Methods: We observed two colonies of *A. dorsata* flight direction and flight activities in each land cover from 9 am–3pm. Honey was harvested from both nests of *A. dorsata* and the pollen in the honey was analyzed using acetolysis procedure. Vegetation analysis in both locations was conducted based on the flight directions of the giant honey bees.

Results: The foraging data of *A. dorsata* showed a difference in the total number of bees between these two land cover types. The number of bees flying out and returning to the nest was higher in Kerinci than in Kampar, while high morning foraging activities were recorded in both land cover types. Furthermore, the foraging activity of the colonies in the PL landscape, i.e., flying out and returning to the nest with and without pollen, decreased at noon. The palynological results of the honey showed that in the PL landscape, pollen diversity was very low and mainly consisted of *Elaeis guineensis* pollen (97%). Meanwhile, pollen types and concentrations were much higher in the FL than in the PL.

Discussion: This result suggests that *A. dorsata* exhibits a more varied foraging behavior in a diverse and heterogeneous landscape in Kerinci compared to a plantation-dominated habitat in Kampar.

KEYWORDS

forest-agriculture landscape, flight activity, flight directions, honey bee conservation, melissopalynology, plantation-dominated landscape, pollen diversity, vegetation analysis

1 Introduction

Insect pollination is one of the most important keys for ecosystem services (Bartholomé and Lavorel, 2019). Bees, in particular, are efficient pollinators due to their ability to carry more pollen than all non-bee taxa (Bernauer et al., 2022). The giant honey bee, *Apis dorsata* Fabricius 1793, is one of the most common pollinators found in subtropical Asia, i.e., China (Sakagami et al., 1980) and Nepal (Thapa, 2001), to the tropical Asia, covers India (Reddy, 1980), Thailand (Wongsiri et al., 1996), Sri Lanka (Koeniger and Koeniger, 1980), Philippine (Ruttner, 1988), including Indonesia (Ruttner, 1988; Nagir et al., 2016; Dyahastuti et al., 2022; Zahara et al., 2022; Kahono et al., 2023). *Apis dorsata* colonies have an essential ecological role in the ecosystem as pollinators for crops and natural plant communities (Rattanawanee et al., 2023). Almost 40 plant species were known to interact with *A. dorsata* in Pakistan (Sajjad et al., 2017). They also pollinate at least 15 plant species in Malaysia (Momose et al., 1998), six and 17 plant species in Thailand (Suwannapong et al., 2013; Stewart et al., 2018), and eight plant species in Indonesia (Bramasta et al., 2023). Considering the large number of workers per colony, hairy body of workers, generalized visitation pattern, floral constancy, and higher flower visitation rate make them effective pollinators (Layek et al., 2023). They also have a high flight range and efficient communication when foraging (Ruttner, 1988). *Apis dorsata* is important for honey hunters in Indonesia as the bees produce economically valuable honey (Schouten et al., 2020).

This giant honey bee is also a keystone species in dipterocarp forests (Rattanawanee et al., 2023). Indonesian archipelagoes were dominated by tall dipterocarp trees of more than 60 m. These forests are characterized by seasonal flowering and the so-called “general flowering,” most canopy trees mass-flower within several months but only every 4–5 years (Appanah, 1993; Sakai et al., 1999). When these events occurred, one of the main flower visitors was found to be *A. dorsata* (Momose et al., 1998). Under natural conditions, in the highly diverse lowland tropical rainforest of Sumatra, *A. dorsata* can select more nutrient-rich flowers and change the target plant following seasonal changes or mass flowering events (Rosmarlinasiah et al., 2015). In Sumatra, the

nesting tree of *A. dorsata* is known by local people as the Sialang tree, which refers to more than one tree species, such as *Koompassia excelsa* (Shwetha et al., 2023) and *Gluta renghas* (Gussuwana et al., 2015; Dyahastuti et al., 2022). However, since the mid-20th century, the rainforests in Sumatra, particularly in the lowland, have been logged on a large scale and heavily converted into monoculture plantations of acacia (*Acacia* sp.), rubber (*Hevea brasiliensis*) and oil palm (*Elaeis guineensis*) (Drescher et al., 2016).

Several studies have shown that the conversion of rainforest to a transformation system affects the foraging behavior of bee pollinators (Gervais et al., 2020; Pulungan et al., 2023). Due to the plantation-dominated landscape, limited support for tree nesting (personal observation), and nectarine flower trees, as shown in the pollen in the honey in this study, might have affected the low number of bee colonies that migrated to Kampar in the past years. Besides that, the high temperature in the studied area reached 40°C, which is unfavorable for this important pollinator in the forest. The high temperature of 40–45°C also triggered the bees in Bengal to migrate in May and June (Singh et al., 2007). In addition to the temperature, rainfall and wind velocity highly influence the migration of *A. dorsata* colonies to safe places (Abrol, 1992). An extensive haze from the forest fire occurred in Riau Sumatra in 2015 and increased the temperature (Lee et al., 2016; Kozan, 2019; Sze et al., 2019). Before 2015, each nesting tree in Kampar, Riau, was home to hundreds of *A. dorsata* (Hotma Barinah, personal communication). After the haze, only a few colonies of *A. dorsata* migrate to the same Sialang trees (Raffiudin, personal observation).

While an extensive rainforest conversion arises in Sumatra, how *A. dorsata* adapts to this land cover is still unknown. Therefore, more studies are needed to improve our understanding of the important role of ecological functions of bee pollinators linked with forest conversion in Indonesia. To understand the effects of land cover on the ecological behavior of *A. dorsata*, our study aimed to (1) investigate the foraging behavior of *A. dorsata* and (2) compare the floral composition of the honey produced by colonies of *A. dorsata* in two land cover types in the transformation systems of plantations landscape (PL) in Kampar (Riau) and the mixed forest-agriculture landscape (FL) in Kerinci (Jambi), Sumatra.

2 Materials and methods

2.1 Study sites

Two locations on the island of Sumatra were selected for the study, i.e., Kampar Regency, Riau Province, and Kerinci Regency, Jambi Province, Indonesia. The first location represented the plantation-dominated landscape (PL) (Figure 1A), while the second represented the forest-agroforest landscape (FL) (Figure 1B). Two colonies per location of *A. dorsata* nested in the Sialang tree (*Gluta renghas*) were studied.

The Kampar site is located in the lowland area (36 m a.s.l) and is surrounded by the *Eucalyptus* and oil palm plantation (Figure 1A). The Kerinci Valley is located in the eastern part of the Kerinci Seblat National Park (KSNP) within the Barisan mountain range. The valley is surrounded by a montane rainforest (850 m a.s.l), farming crops such as hot pepper and coffee plantations (Figure 1B).

2.2 Observation of *A. dorsata* foraging behavior

The foraging behavior of two of *A. dorsata* colonies in Kampar and Kerinci was observed at their nesting tree in the rainy season of September–November 2017. We counted the number of bees flying out of the nest (FO), returning into the nest without pollen (RWoP), returning into the nest with pollen (RWP), and the flight directions (FD) from the tree house. The height of the tree house was around 20–30 m above the ground, which was the same height as the nest that we observed. The tree house is around 10 meters away from the nest of *A. dorsata*. We observed the *A. dorsata* flying out and returning with and without pollen at the bottom of the comb, approximately covering 20% of the area of the *A. dorsata* nest.

Observation of foraging activities was conducted from 9.00 am to 3.00 pm with 10-minute observation intervals in 4 days. The foraging time of *A. dorsata* is started in the early morning

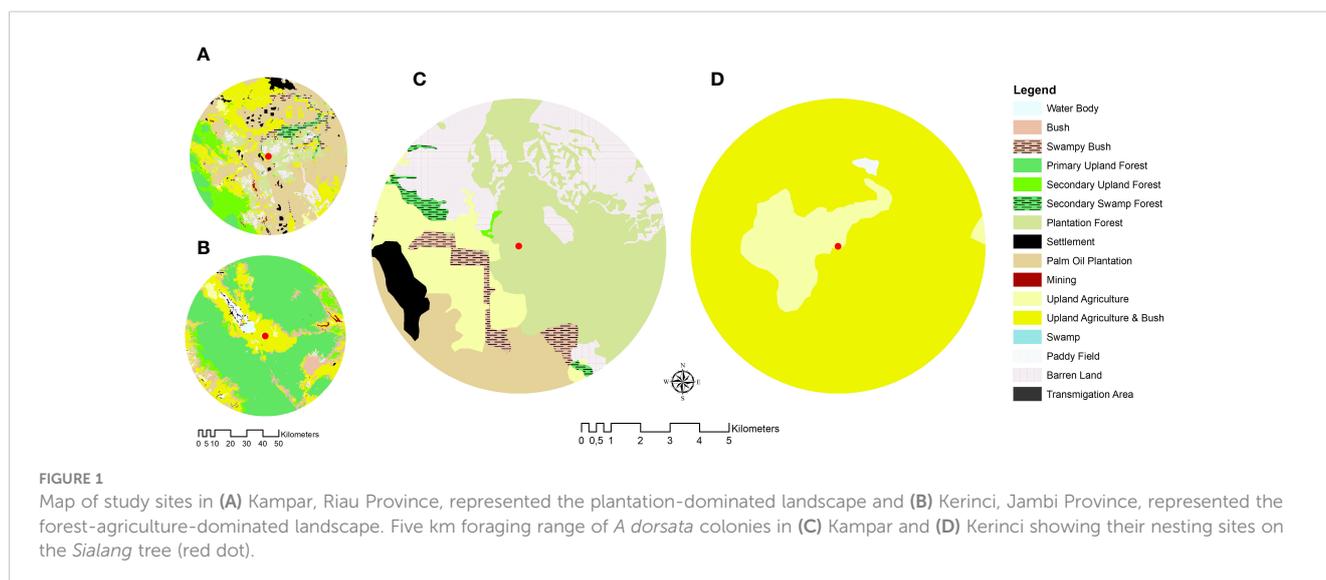
(Rattanawanee et al., 2023). However, for safety reasons, we collected foraging behavior data between 9.00 am and 3.00 pm.

2.3 Collection of honey samples

We collected honey from two colonies each in Kampar and Kerinci on the last observation day of *A. dorsata* foraging behavior. From each colony, we harvested 450 mL of honey samples for melissopalynological analysis. The wax that covered the honey part of the nest was sliced to release the honey. Honey was kept in a storage jar for further melissopalynological analyses.

2.4 Pollen analysis

Melissopalynological analyses were conducted on those four honey samples. Pollen in honey was extracted from 3 mL of honey (Louveaux et al., 1978). Each subsample consists of one tablet of *Lycopodium clavatum* spores to estimate pollen concentrations (Stockmarr, 1971). The method includes acetolysis to improve the visualization of diagnostic features, which is essential to pollen identification of tropical taxa (Erdtman, 1972). Additionally, untreated samples were checked for pollen taxa that did not preserve acetolysis (e.g., pollen grains from the Lauraceae family). Pollen was counted up to a total sum of at least 1200 pollen grains per subsample to obtain pollen spectra of the floral resources foraged by the bees in the period before collection (Louveaux et al., 1978). Pollen identification was then conducted based on morphological characteristics using the modern reference collection of pollen and spores from the University of Jambi (Indonesia) and the Georg-August University of Goettingen (Germany). This database includes ca. 130 pollen taxa and 45 spores from lowland and mountain rainforests, oil palm and rubber plantations, and coastal and peatland forests from Sumatra Island. Additionally, we used online pollen databases of Australasia Pollen and Spore Atlas (<http://apsa.anu.edu.au/>).



2.5 Vegetation analysis and index diversity

The transect direction for vegetation analysis was based on the fly direction of the bees. Eleven plots were made in Kampar and Kerinci, which comprise four subplots: (a) tree plots (20 m x 20 m), (b) pole plots (10 m x 10 m), (c) sapling plot (5 m x 5 m), and (d) seedling plot (2 m x 2 m).

In our attempt to determine the vegetation of the remnant forest in Kampar and Kerinci, we analyzed vegetation through the Importance Value Index (IVI), which shows the dominant plant species in a specific region. Based on the vegetation recorded, the Important Value Index was calculated on the sum of relative density (RD), relative frequency (RF), and relative dominance (RDo) for poles and trees. Meanwhile, seedlings and saplings were calculated based on relative density (RD) and relative frequency (RF) (Gonçalves et al., 2018). The Shannon diversity index (H') was also calculated to determine plant diversity in Kampar and Kerinci based on recorded plant species from 11 plots (Shannon, 1948). All of the parameters in the vegetation analysis were calculated using the following formulas:

$$\text{Relative Density (RD)} = \frac{\sum \text{species } i}{\sum \text{all species}} \times 100 \%$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency species } i}{\sum \text{frequency all species}} \times 100 \%$$

$$\text{Relative Dominance (RDo)} = \frac{\text{Basal area species } i}{\sum \text{basal area all species}} \times 100 \%$$

$$\begin{aligned} \text{Important Value Index (IVI) for trees and poles} \\ = \text{RD} + \text{RF} + \text{RDO} \end{aligned}$$

Important Value Index (IVI) for saplings and seedlings = RD + RF

$$\text{Shannon Diversity Index (H')} = - \sum [(pi) \times \ln(pi)]$$

2.6 Statistical analysis

The correlation of environmental factors, i.e., temperature, humidity, and light intensity with the foraging activities of each *A. dorsata* colony in Kampar and Kerinci was performed using General Linear Models (GLM) with a Gaussian distribution in R package (R Core Team, 2018).

3 Results

3.1 Foraging behavior of *Apis dorsata* in Kampar and Kerinci

The foraging behavior of *A. dorsata* in Kampar showed that the two colonies peaked in their flight activity from 10:00 to 11:00 am with an average number of about 385 individuals in colony 1

(Figure 2A) and 198 individuals in colony 2 (Figure 2B). Foraging decreased from 12.00-13.00 h, with only 46 bees flying out in colony 1 (Figure 2A) and 35 bees in colony 2 in one hour (Figure 2B). Similarly, bee activities in Kerinci peaked from 10.00 h to 11.00 h with 427 individuals in colony 1 (Figure 2C) and 504 individuals in colony 2 (Figure 2D). *Apis dorsata* foraging activities in Kerinci decreased from ca. 11.00-12.00 h. However, the bee numbers in Kerinci are 3-4 times higher compared to Kampar, i.e., 192 bees flying out in colony 1 (Figure 2C) and 191 in colony 2 (Figure 2D). The individuals returning into the nest without pollen (RWoP: 360 and 263) and returning with pollen (RWP: 230, 340) in both colonies in Kerinci were two times larger compared to those in both colonies in Kampar (RWoP: 173, 150 and RWP: 120, 258) during the peak of foraging from 10.00-11.00 h (Figures 2A-D). Therefore, this study revealed that the land cover diversity affected the decrease in flight activities of this giant honey bee, flying out and returning to the nest with and without pollen.

The nesting tree of *A. dorsata* in Kampar was close to the large oil palm plantation. It was in a remnant forest surrounded by *Eucalyptus* and oil palm plantations (Figures 1A, 3A). The flight direction of forager bees during the peak foraging time of colonies 1 and 2 in Kampar was south and southwest, respectively (Figures 1C, 3C). On the other hand, the nesting tree of *A. dorsata* colonies in Kerinci was surrounded by montane rainforest vegetation and agricultural plantations (Figures 1B, 3B). Based on our observation, both *A. dorsata* colonies in Kerinci were flying out to the south and southeast directions from the nest tree (Figures 1D, 3D).

The GLM analysis shows the correlation between *A. dorsata* foraging behavior and environmental factors such as temperature, humidity, and light intensity (Supplementary Table 1). It indicates that the foraging activities of *A. dorsata* in Kampar and Kerinci have similar trends, i.e., being negatively influenced by humidity and positively correlated with temperature and light intensity. However, these values were not significant, except for a few measurements.

3.2 Pollen analysis

Honey of *A. dorsata* from the landscape dominated by plantations in Kampar showed a low concentration of pollen, i.e., no more than 50.000 pollen grains/mL (Figure 4A). Colony 1 has low pollen concentration with an average of 11.502 grains/mL, while colony 2 has almost four times more pollen concentration. Only three pollen taxa are identified from the honey of *A. dorsata* in the Kampar site (Figures 4B, 5A, B). The pollen was dominated by 95-97% *Elaeis guineensis*, followed by 2-5% Myrtaceae and <0.5% *Acacia* type (Figures 6A-C).

Pollen concentration in both bee colonies in the forest-agriculture dominant landscape in Kerinci was almost seven times higher than in Kampar (Figure 4A), which is reflected in the differences between the monoculture plantation area in Kampar and the agroforestry landscape in Kerinci. The number of pollen types in the honey samples from Kerinci was significantly higher than in Kampar, with 16 and 13 different pollen taxa found in colony one and colony 2 of *A. dorsata*, respectively (Figures 4B, 5C, D). Among those pollen types, *Ilex* type and Asteraceae pollen grains are co-dominant (Figures 5C, D, 6D-F).

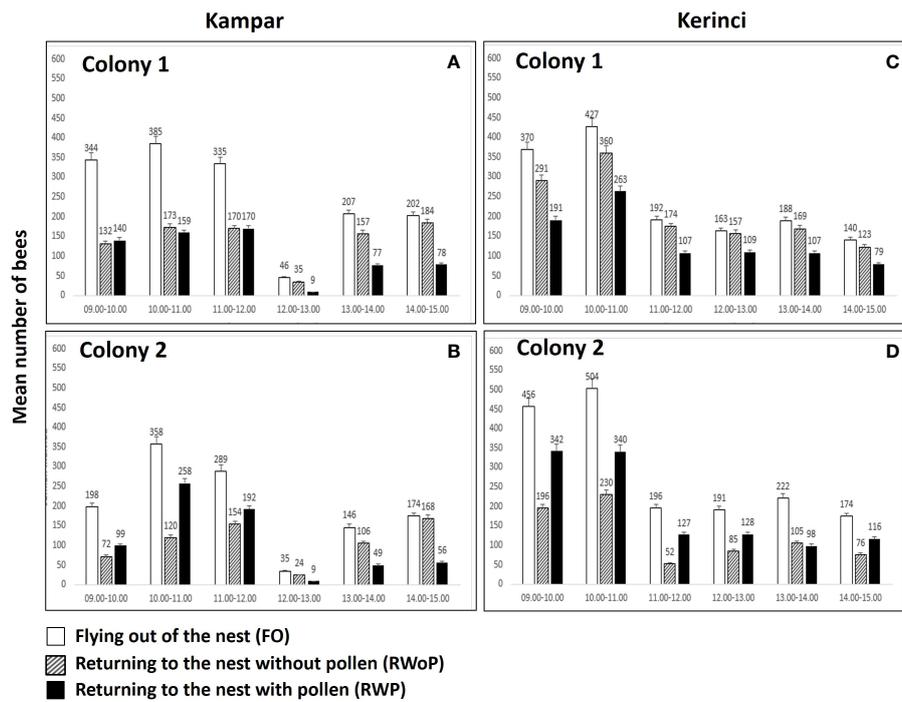


FIGURE 2 Mean and std number of foraging bees of *A. dorsata* in (A, B) Kampar and (C, D) Kerinci.

3.3 Vegetation analysis

A higher plant diversity was found in Kerinci, with a high 3.19 H' , compared to Kampar, with H' 2.58 (Table 1). The vegetation analysis in Kampar showed that the dominant tree species is *Artocarpus maingayi* (Moraceae), with a 51% IVI value, while *Alseodaphne* sp. dominated the pole with a 42% IVI value. We found a very high

dominance of Fabaceae in saplings and seedlings, with 114% and 107% IVI values, respectively (Supplementary Table 2).

The dominant tree species in Kerinci is *Ficus* sp. (Moraceae), with a 56% IVI value, while pole vegetation was dominated by *Knema cinerea* (46%). *Coffea* sp. was dominated in sapling and seedling vegetations with 47% and 109% IVI values, respectively (Supplementary Table 3).

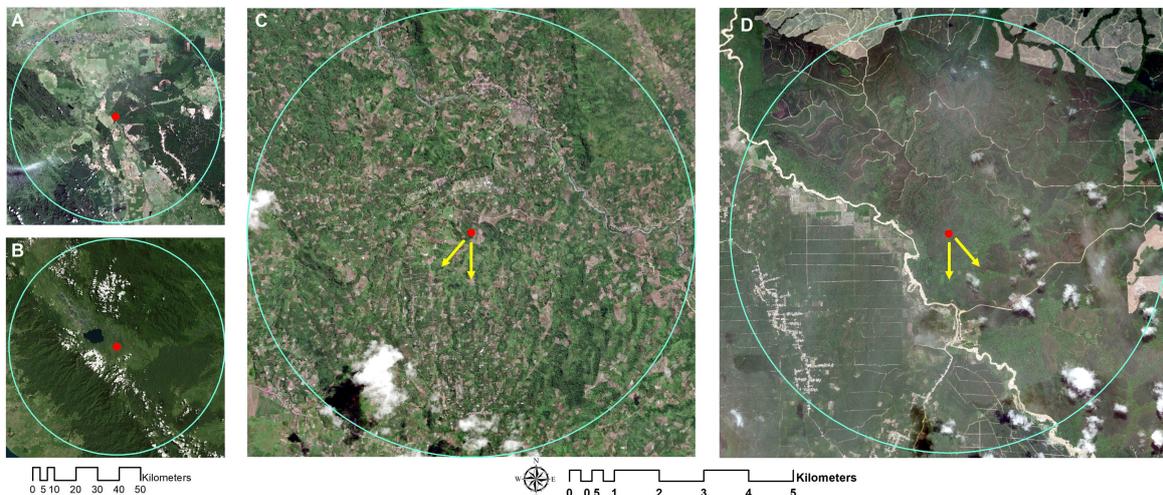


FIGURE 3 The position of *A. dorsata* nest in (A) Kampar and (B) Kerinci. The red dot indicates the nest position in the *Sialang* tree, and the yellow arrow indicates foraging directions in (C) Kampar: south and southwest and (D) Kerinci: south and southeast. Google Earth captured: January 2018.

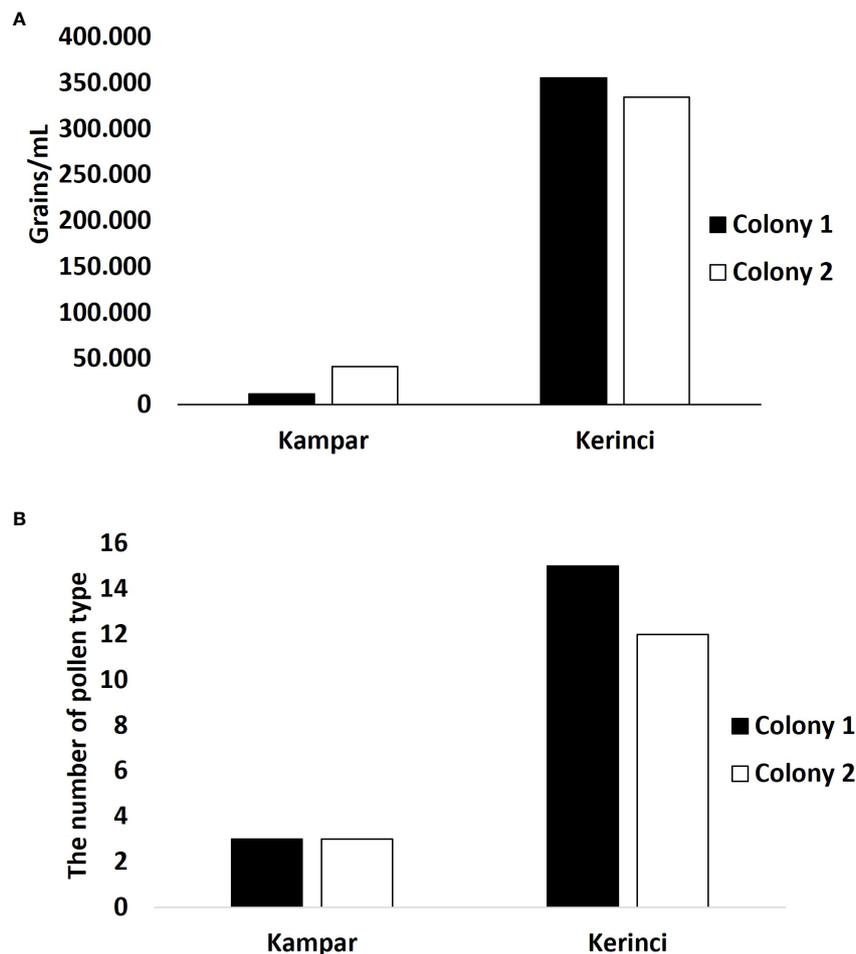


FIGURE 4
Pollen quantification and identification from *A. dorsata* honey from Kampar and Kerinci. (A) Pollen concentration and (B) The number of pollen types.

4 Discussion

This study attempted to answer the question of how *A. dorsata* adapts to different land covers. Overall, the lowland rainforests in Sumatra converted into plantations of oil palm, rubber, and acacia (Drescher et al., 2016). Our study revealed that the land cover transformation in Kampar affected *A. dorsata* behavior; the giant honey bee flew mainly to the oil palm plantation (Figure 3A) to reach the pollen, as shown in the melissopalynological results (Figures 6A, B). Even though the distance between the nest of *A. dorsata* was approximately 1.9 km to the nearest oil palm plantation (Figures 1C, 3C). This long-distance flight to collect the oil palm pollen was also shown by *A. dorsata* in Kampar Island flying across the strait to reach the oil palm plantation in Belitung Regency (Bramasta et al., 2023). Indeed, *Apis dorsata* can also have long-distance flights during migration across continents (Robinson, 2012, 2021). Oil palm pollen is the typical source of *A. dorsata* in Marang, Terengganu, Malaysia, even though it is in a tropical rainforest (Ibrahim et al., 2012). The experiment of *A. dorsata* foraging distance in Bangalore, India, showed a shorter distance according to the habitat. The bees preferred to forage in the garden

with a distance of 800-900 m due to the various cultivated flowering plants (Young et al., 2021b). In accordance, *A. mellifera* foraged at a shorter distance during the major flowering seasons compared to the non-flowering seasons (Couvillon et al., 2015).

Our observations of two colonies of *A. dorsata* in each location of the landscape are nesting in the same aggregation of a tree. Although both colonies are foraging in the same direction, colonies within aggregation might not be related to mother and daughter colonies; this was shown in the *A. dorsata* aggregated colonies in the same tree in Assam, India. By using microsatellite DNA, Paar et al. (2004) revealed that the colonies apparently are not genetically related. Due to the high genetic differentiation among the bee colonies, the management of the conservation should be carefully taken, especially since these giant honey bees migrate to their home at the same site in the coming year (Paar et al., 2000).

Both *A. dorsata* colonies in the same aggregation in the plantation-dominated landscape (PL) in Kampar were dominated by oil palm pollen, although in low concentrations (Figure 4A). The low concentration also indicates a lack of pollen availability in the surrounding nest area, supported by a moderate plant diversity index (Table 1). Given the absence of a nectarine gland in oil palm

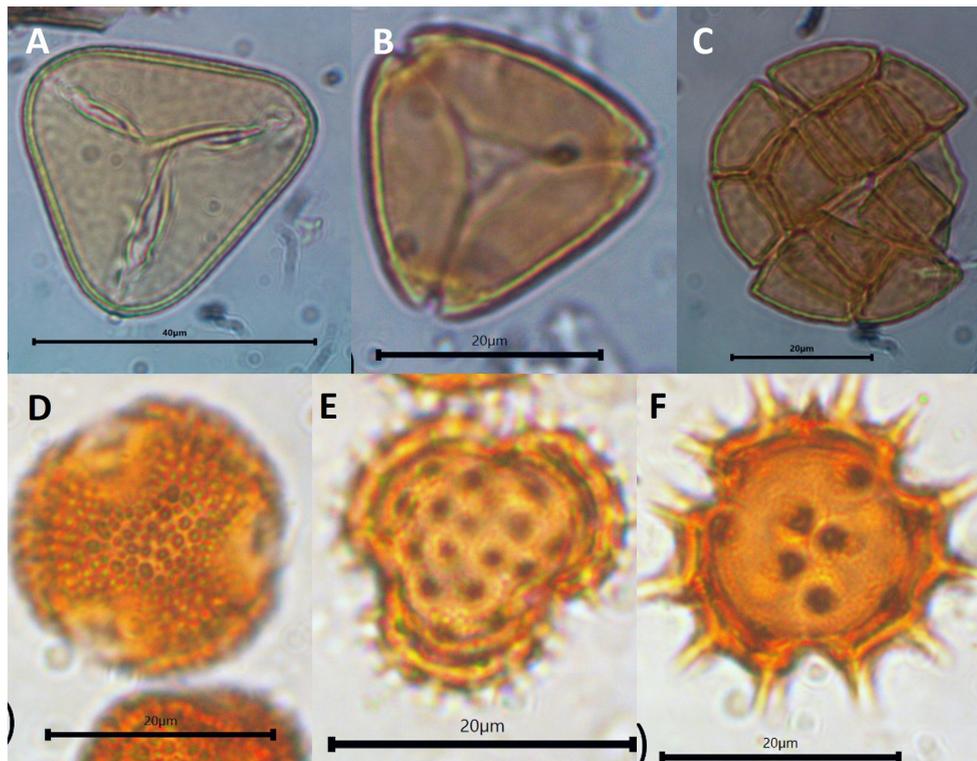


FIGURE 5 Morphology of dominant pollen contained in *A. dorsata* honey. (A) *Elaeis guineensis*, (B) Myrtaceae, and (C) *Acacia* found in the Kampar honey, (D) *Ilex* type, and Asteraceae (E, F) were dominant in Kerinci.

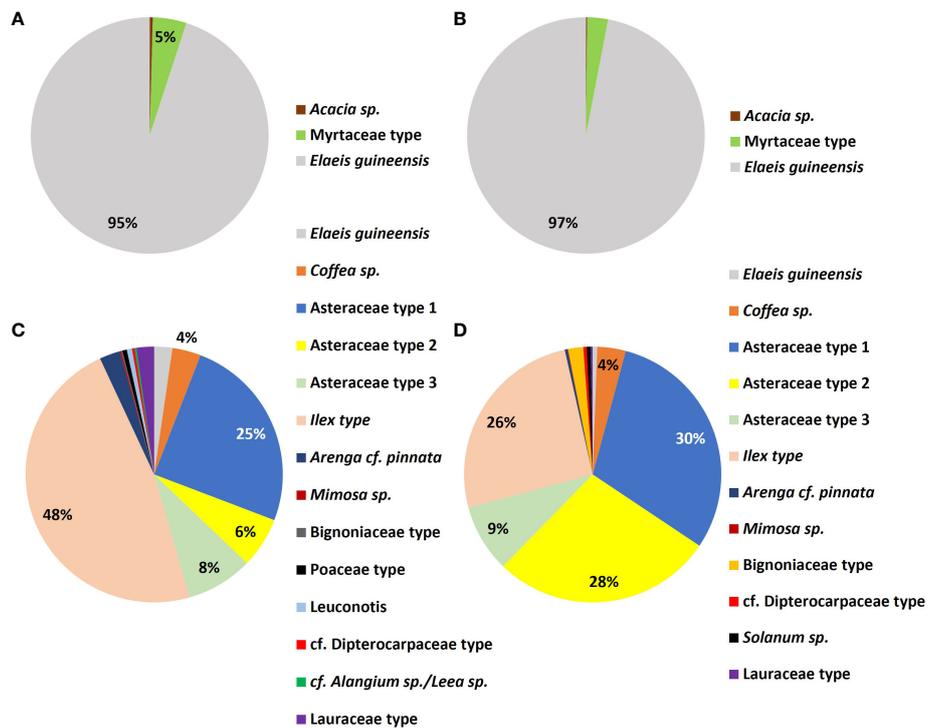


FIGURE 6 Pollen composition and pollen percentage of *A. dorsata* honey from (A, B) Kampar and (C, D) Kerinci. Pollen percentages below 4% are not shown.

TABLE 1 Shannon diversity index of plant species surrounding nesting tree of *A. dorsata* in Kampar and Kerinci.

No	Location	Land cover type	The number of plant species	Diversity index (H')	Diversity level
1	Kampar	Plantation-dominated landscape	39	2.58	Moderate
2	Kerinci	Forest-agriculture-dominated landscape	59	3.19	High

(Silberbauer-Gottsberger, 1990), *A. dorsata* and other pollinators might suffer from the lack of important resources in the vicinity of the nest. The nectar resource in Kampar Riau remains unknown. However, it is possibly represented by the Myrtaceae species (Freitas et al., 2016) due to it being the second most abundant pollen grain found in the honey samples (Figures 6A, B). In the studied area of plantation-dominated landscape (Kampar), a hundred hectares of monoculture, *Eucalyptus* (Myrtaceae) is the nectar source. Myrtaceae is one of the nectar sources foraged by *A. dorsata* in West Bengal, India (Layek and Karmakar, 2018) and also in Kampak Island, Belitung, Indonesia (Bramasta et al., 2023).

We found that the pollen concentration of the honey from FL Kerinci was ten times higher compared to the PL in Kampar (Figure 4A). This finding was supported by the high foraging activity of *A. dorsata* in Kerinci (Figures 2C, D), which might have influenced the pollen concentration in honey. An experimental study of honey bee *A. mellifera* revealed that the amount and rate of pollen and nectar collection were positively correlated with the individual foraging experience of the bees (Klein et al., 2019). In addition, relationship analysis between the pollen contained in honey and vegetation types in the West Coast (WC) and Western Ghats (WG), India, revealed that floral resources also affected pollen concentration in honey (Hegde et al., 2023). *Apis indica* honey from the more diverse vegetation of the WG, showed a higher pollen concentration compared to those from the WC, which has less diverse vegetation (Hegde et al., 2023). In contrast, *A. dorsata* and *A. florea* honey from the less diverse vegetation of WC contained a higher pollen concentration compared to those from more diverse vegetation of WG. Thus, we suggest that the higher pollen concentration in *A. dorsata* honey from Kerinci could be shaped by two factors, i.e., different flower (pollen) resources and the foraging activities of the bees. This result was supported by a high number of pollen taxa found in the honey from forest-agriculture-dominated landscapes (FL) in Kerinci, which revealed more diversified pollen collected by the foraging honey bees with a total of sixteen pollen types (Figures 4B, 6C, D). Our result is concordant with the honey of *A. dorsata* produced in the more diverse vegetation of deciduous forests in Western Ghats, India, which contains a more diverse pollen type compared to the honey produced in less diverse vegetation in West Coast India (Hegde et al., 2023). No predominant pollen taxon was found in the FL Kerinci. Thus, our results in FL Kerinci suggest an admixture of open grassland and forest resources with the agriculture of coffee plantations surrounding the forest of the nesting trees of *A. dorsata* (Supplementary Table 3). We found the *Coffee* sp. pollen in a low percentage in *A. dorsata* honey in FL Kerinci (Figures 6C, D). Coffee flowers are also foraged by *A. dorsata binghami* in the agroecosystem near Lore Lindu National Park, Central Sulawesi

(Klein et al., 2002). Besides *A. dorsata*, the flower of *Coffee* sp. was also pollinated by the native cavity-nesting Asian honey bee *A. cerana* (Saepudin, 2014; Sari and Putra, 2015). *Apis dorsata* might pollinate a lesser number of plant species compared to the other Asian honey bees, *A. cerana* and *A. florea* (Stewart et al., 2018). This is presumably due to the *A. dorsata* needs mass flowering plants despite the lower number of plant species. This giant honey bee needs much more pollen due to the larger colony size compared to *A. cerana* and *A. florea* (Stewart et al., 2018).

The maximum foraging activity of *A. dorsata* occurred during morning times in both landscapes, while the minimum activity occurred at noon (Figure 2). Foraging observation of *A. dorsata* on blooming *Eucalyptus* in South Gujarat, India, revealed the same phenomenon: the maximum and minimum foraging activity of *A. dorsata* occurred in the morning and during midday, respectively (Behera et al., 2018). Moreover, an extensive observation of *A. dorsata* foraging activity in Bangalore, India, revealed that the foraging peaks occurred during the morning (before 9 am) and evening twilight (after 5 pm) and still exhibit the foraging activity during the night time (Young et al., 2021a). The nocturnal activities of *A. dorsata* are supported by their higher eye sensitivity compared to *A. cerana* and *A. florea* (Somanathan et al., 2009). In addition, the flight activity of *A. dorsata* in forest-agriculture-dominated landscapes was three times higher than in plantation-dominated landscapes at noon (Figure 2). This is presumably due to the blooming flowering plants surrounding the nesting tree in FL Kerinci (Supplementary Table 3), which was also supported by the higher plant diversity in Kerinci compared to Kampar (Table 1). This phenomenon in Kerinci might be due to the high nectar-sugar concentration that positively influences the foraging activity of *A. dorsata* (Abrol, 1992).

Besides nectar-sugar concentration, our result revealed that the foraging activity of *A. dorsata* was also positively affected by temperature and light intensity and negatively affected by humidity. The same pattern of environmental influence also occurred in the foraging time of *A. dorsata* in India (Abrol, 1992). On the other hand, we found a lack of blooming flowering plants in the Kampar location due to the high domination of Fabaceae seedlings surrounding the nesting tree. The high domination of Fabaceae seedlings represented by the highest IVI value in Kampar (Supplementary Table 2) is presumably due to the high usage of Fabaceae plants for rehabilitation of the transformed land in Indonesia, including Sumatra (Wiriyono et al., 2022).

In our study, *A. dorsata* in Kerinci migrates in March, and the highest number of migrations is in April-May (unpublished data). The blooming flowering plants are important for the survival of the bees, thus attracting them to migrate to their previous nesting site (Paar et al., 2004). The migration of *A. dorsata* is from October to

June, which depends on the source of nectar flowering plants (Singh et al., 2007). While in Borneo, *A. dorsata* migrate after one-month peak flowering (Itioka et al., 2001). Different flowerings in certain seasons were found in West Bengal, India, attracting giant bees to migrate (Layek and Karmakar, 2018). In summer, the predominant pollen type that attracts the most is the blooming of *Eucalyptus*. In winter, *Brassica* sp. is predominant, followed by *Borassus* sp. in spring (Layek and Karmakar, 2018). The plant resources for *A. dorsata* in Mount Tinanggo Kolaka Southeast Sulawesi found a total of 237 types of flowering plants, and September is the flowering peak (Rosmarlinasiah et al., 2015).

Natural forests are dominant landscape habitats that provide nesting trees and food resources for honey bee species (*A. dorsata*, *A. mellifera*, and *A. cerana*). Based on our results, the composition of land cover in Kerinci, which is still dominated by natural forest, supported more pollen sources from different plant species (16 pollen types) for *A. dorsata* than the composition of plantation-dominated landscape in Kampar (3 pollen types) (Figure 6). A similar pattern also occurred in *A. mellifera*, where the forest landscape increased the diversity in honeybee diets, particularly trees, which were the dominant floral source of bee bread (Cannizaro et al., 2022). *Apis cerana* also collected more pollen types as a food diet in deciduous forests (16-28 pollen types) than in agricultural regions (9-16 pollen types) (Jhansi et al., 1994). Land cover transformation, such as natural forests to oil palm plantations, change pollination as the habitat function loss (Dislich et al., 2016) and the loss of biodiversity (Meijaard et al., 2018). Land cover change from forest to other land cover could change the diet of bees and might lead to loss of pollination services (Atmowidi et al., 2007; Pot et al., 2010) where honey bees are known as crucial pollinators (Kovács-Hostyánszki et al., 2018). A study on pollination services revealed that *Apis dorsata* has an essential role in compensating for stingless bee decline as critical pollinators during drought season in agricultural land in Bangalore, India (Mukherjee et al., 2019).

Our investigation concluded that the effect of land cover on the pollen diversity in the honey of *A. dorsata* related to pollen source with flight direction of the bees from a landscape perspective. The differences in environment can give empirical data to identify flower resources used by *A. dorsata*. Moreover, the information on floral resources used by *A. dorsata* is crucial for establishing a deterministic link between land cover, plant composition, and pollinator population development. The foraging activities of *A. dorsata* in the plantation-dominated landscape in Kampar showed low flight activities, particularly during the noon. The pollen results in the honey from Kampar show low diversity and concentration. While in the forest-agriculture-dominated landscape, this giant honey bee showed high flight activities. The pollen analysis from the honey harvested in this area revealed high pollen concentration and diversity of pollen types.

Although our research did not cover the natural habitat of *A. dorsata*, the result revealed a more diversified foraging behavior of *A. dorsata* in a more diverse heterogenetic landscape compared to the monoculture habitat. Our comprehensive study of foraging behavior, melissopalynology, and vegetation analysis in two land cover types proposes that enriching plant diversity around plantation habitats is needed to increase flower resources for *A. dorsata*. In this way, the

sustainability of socioeconomic and ecological functions in plantation-dominated landscapes is expected to be enhanced.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author/s.

Ethics statement

Ethical approval was not required for the study involving animals in accordance with the local legislation and institutional requirements because the research method employed involved observation of the foraging behavior of honey bee *Apis dorsata*.

Author contributions

RR: Conceptualization, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. MD: Formal analysis, Investigation, Project administration, Writing – review & editing. RN: Formal analysis, Investigation, Methodology, Project administration, Writing – review & editing. TS: Formal analysis, Writing – original draft, Writing – review & editing. ND: Methodology, Writing – review & editing. ES: Formal analysis, Investigation, Visualization, Writing – review & editing. VA: Formal analysis, Investigation, Visualization, Writing – review & editing. RM: Formal analysis, Investigation, Visualization, Writing – review & editing. SB: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – review & editing. CS: Formal analysis, Writing – review & editing. LP: Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. WP: Resources, Writing – review & editing. TA: Supervision, Writing – review & editing. AS: Writing – review & editing. HB: Conceptualization, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/frbee.2024.1366287/full#supplementary-material>

SUPPLEMENTARY TABLE 1

Correlation of *A. dorsata* foraging with environmental factors.

SUPPLEMENTARY TABLE 2

Important Value Index of plant species in Kampar region.

SUPPLEMENTARY TABLE 3

Important Value Index of plant species in Kerinci region.

References

- Abrol, D. P. (1992). Foraging honeybees in *Apis cerana indica* F. and *A. dorsata* F. (Hymenoptera: apidae)-activity and weather conditions. *J. Ind. Inst. Sci.* 72, 395–401.
- Appanah, S. (1993). Mass flowering of dipterocarp forests in the seasonal tropics. *J. Biosci.* 18, 457–474. doi: 10.1007/BF02703079
- Atmowidi, T., Buchori, D., Manuwoto, S., Suryobroto, B., and Hidayat, P. (2007). Diversity of pollinator insects in relation to seed set of mustard (*Brassica rapa* L.: Cruciferae). *HAYATI J. Biosci.* 14, 155–161. doi: 10.4308/hjb.14.4.155
- Bartholomée, O., and Lavorel, S. (2019). Disentangling the diversity of definitions for the pollination ecosystem service and associated estimation methods. *Ecol. Indic.* 107, 105576. doi: 10.1016/j.ecolind.2019.105576
- Behera, L. K., Mehta, A. A., Dholaria, C. A., Patel, S. M., and Gunaga, R. P. (2018). Foraging activity of Rockbee (*Apis dorsata*) on *Eucalyptus*: A promising MPTs in South Gujarat condition. *J. Entomol. Zool. Stud.* 6, 550–553.
- Bernauer, O. M., Tierney, S. M., and Cook, J. M. (2022). Efficiency and effectiveness of native bees and honey bees as pollinators of apples in New South Wales orchards. *Agric. Ecosyst. Environ.* 337, 108063. doi: 10.1016/j.agee.2022.108063
- Bramasta, D., Qayim, I., Djuita, N. R., Raffiudin, R., Putra, R. E., Soesilohadi, R. H., et al. (2023). Melissopalynology and vegetation analysis surrounding sunggau of giant honey bee *Apis dorsata* in Belitung Regency. *HAYATI J. Biosci.* 30, 1167–1174. doi: 10.4308/hjb.30.6.1167-1174
- Cannizaro, C., Keller, A., Wilson, R. S., Elliott, B., Newis, R., Ovah, R., et al. (2022). Forest landscapes increase diversity of honeybee diets in the tropics. *For. Ecol. Manage.* 504, 119869. doi: 10.1016/j.foreco.2021.119869
- Couvillon, M. J., Riddell Pearce, F. C., Acclerton, C., Fensome, K. A., Quah, S. K. L., Taylor, E. L., et al. (2015). Honey bee foraging distance depends on month and forage type. *Apidologie* 46, 61–70. doi: 10.1007/s13592-014-0302-5
- Dislich, C., Keyel, A. C., Salecker, J., Kisel, Y., Meyer, K. M., Auliya, M., et al. (2016). A review of the ecosystem functions in oil palm plantations, using forests as a reference system. *Biol. Rev.* 92, 1539–1569. doi: 10.1111/brv.12295
- Drescher, J., Rembold, K., Allen, K., Beckschäfer, P., Buchori, D., Clough, Y., et al. (2016). Ecological and socioeconomic functions across tropical land use systems after rainforest conversion. *Phil. Trans. R. Soc. B.* 371, 20150275. doi: 10.1098/rstb.2015.0275
- Dyahastuti, M., Raffiudin, R., Widjaja, M. C., Afriani, N., and Listyowati, S. (2022). Flight activity before migration and pollen identification from honey of *Apis dorsata* in Kampar, Riau. *Jurnal Sumber Daya Hayati.* 8, 34–41. doi: 10.29244/jsdh.8.2
- Erdtman, G. (1972). *Pollen Morphology and Plant Taxonomy* (New York: Hafner Publishing).
- Freitas, M. L., Dutra, M. B., and Bolini, H. M. (2016). Sensory profile and acceptability for pitanga (*Eugenia uniflora* L.) nectar with different sweeteners. *Food Sci. Technol. Int.* 22, 720–731. doi: 10.1177/1082013215607077
- Gervais, A., Courtouis, E., Fournier, V., and Belisle, M. (2020). Landscape composition and local floral resources influence foraging behavior but not the size of *Bombus impatiens* Cresson (Hymenoptera: Apidae) workers. *PLoS One* 15, e0234498. doi: 10.1371/journal.pone.0234498
- Gonçalves, F. M. P., Revermann, R., Cachissapa, M. J., Gomes, A. L., and Aidar, M. P. M. (2018). Species diversity, population structure, and regeneration of woody species in fallows and mature stands of tropical woodlands of southeast Angola. *J. For. Res.* 29, 1569–1579. doi: 10.1007/s11676-018-0593-x
- Gussuwana, I., Yoza, D., and Mardhiansyah, M. (2015). The characteristic of beehive trees and the preference of bee nesting in the beehive surround forest of Gunung Sahilan Village, Gunung Sahilan District, Kampar Regency, Riau Province. *J.O.M* 2, 1–8.
- Hegde, S., Sharathchandra, K., and Sridhar, K. R. (2023). Honey-producing bee-pollen-vegetation relationships in the West Coast and Western Ghats of India. *Palynology* 47, 2127957. doi: 10.1080/01916122.2022.2127957
- Ibrahim, I. F., Balasundram, S. K., Abdullah, N. A. P., Alias, M. S., and Mardan, M. (2012). Morphological characterization of pollen collected by *Apis dorsata* from a tropical rainforest. *Int. J. Bot.* 8, 96–106. doi: 10.3923/ijb.2012.96.106
- Itoika, T., Inoue, T., Kaling, H., Kato, M., Nagamitsu, T., Momose, K., et al. (2001). Six-year population fluctuation of the giant honey bee *Apis dorsata* (Hymenoptera: Apidae) in a tropical lowland dipterocarp forest in Sarawak. *Ann. Entomol. Soc. Am.* 94, 545–549. doi: 10.1603/0013-8746(2001)094[0545:SYFOT]2.0.CO;2
- Jhansi, P., Kalpana, T. P., and Ramanujam, C. G. K. (1994). Pollen analysis of some *Apis cerana* Fabr honeys from Andhra Pradesh, India. *Apidologie* 25, 289–296. doi: 10.1051/apido:19940303
- Kahono, S., Peggie, D., Lamerkabel, J. S. A., and Engel, M. S. (2023). "Diversity, recent distribution, and nesting behavior of giant honeybees in Indonesia and their role in natural and agricultural ecosystems," in *Role of Giant Honeybees in Natural and Agricultural Ecosystems*. Ed. D. P. Abrol (CRC Press, Boca Raton, FL), 292–304.
- Klein, A., Steffan-Dewenter, I., Buchori, D., and Tschamtkke, T. (2002). Effects of land use intensity in tropical agroforestry systems on coffee flowering-visiting and trap nesting bees and wasp. *Conserv. Biol.* 16, 1003–1014. doi: 10.1046/j.1523-1739.2002.00499.x
- Klein, S., Pasquarea, C., He, X. J., Perry, C., Sovik, E., Devaud, J. M., et al. (2019). Honey bees increase their foraging performance and frequency of pollen trips through experience. *Sci. Rep.* 9, 6778. doi: 10.1038/s41598-019-42677-x
- Koeniger, N., and Koeniger, G. (1980). Observations and experiments on migration and dance communication of *Apis dorsata* in Sri Lanka. *J. Apic. Res.* 19, 21–34. doi: 10.1080/00218839.1980.11099994
- Kovács-Hostyánszki, A., Földesi, R., Báldi, A., Endrédi, A., and Jordán, F. (2018). The vulnerability of plant-pollinator communities to honeybee decline: A comparative network analysis in different habitat types. *Ecol. Indic.* 97, 35–50. doi: 10.1016/j.ecolind.2018.09.047
- Kozan, O. (2019). Assessment of the health impacts of haze pollutants caused by peatland fires. *Newslett. Towards Regen. Trop. Peatland Societies.* 6, 1–4.
- Layek, U., Das, N., Mondal, R., and Karmakar, P. (2023). "Distribution, nesting biology, and floral preference of giant honeybee (*Apis dorsata* Fabricius) in Southern West Bengal, India," in *Role of Giant Honeybees in Natural and Agricultural Ecosystems*. Ed. D. P. Abrol (CRC Press, Boca Raton, FL), 305–323.

- Layek, U., and Karmakar, P. (2018). Pollen analysis of *Apis dorsata* Fabricius honeys in Bankura and Paschim Medinipur districts, West Bengal. *Grana* 57, 298–310. doi: 10.1080/00173134.2017.1390604
- Lee, J. S. H., Jaafar, Z., Tan, A. K. J., Carrasco, L. R., Ewing, J. J., Bickford, D. P., et al. (2016). Toward clearer skies: Challenges in regulating transboundary haze in Southeast Asia. *Environ. Sci. Policy* 55, 87–95. doi: 10.1016/j.envsci.2015.09.008
- Louveaux, J., Maurizio, A., and Vorwohl, G. (1978). Methods of melissopalynology. *Bee World* 59, 139–157. doi: 10.1080/0005772X.1978.11097714
- Meijaard, E., Garcia-Ulloa, J., Sheil, D., Wich, S. A., Carlson, K. M., Juffe-Bignoli, D., et al. (2018). *Oil palm and biodiversity: a situation analysis by the IUCN Oil palm Task Force*. (Gland, Switzerland: International Union for Conservation of Nature and Natural Resources (IUCN)). doi: 10.2305/IUCN.CH.2018.11.en
- Momose, K., Yumoto, T., Nagamitsu, T., Kato, M., Nagamasu, H., Sakai, S., et al. (1998). Pollination biology in a lowland dipterocarp forest in Sarawak, Malaysia. I. Characteristics of the plant-pollinator community in a lowland dipterocarp forest. *Am. J. Bot.* 85, 1477–1501. doi: 10.2307/2446404
- Mukherjee, R., Deb, R., and Devy, S. M. (2019). Diversity matters: Effects of density compensation in pollination service during rainfall shift. *Ecol. Evol.* 29, 9701–9711. doi: 10.1002/ece3.5500
- Nagir, M. T., Atmowidi, A., and Kahono, S. (2016). The distribution and nest-site preference of *Apis dorsata binghami* at Maros Forest, South Sulawesi, Indonesia. *J. Insect Biodivers.* 4, 1–14. doi: 10.12976/jib/2016.4.23
- Paar, J., Oldroyd, B. P., Huettinger, E., and Kastberger, G. (2004). Genetic structure of an *Apis dorsata*. *J. Hered.* 95, 119–126. doi: 10.1093/jhered/esh026
- Paar, J., Oldroyd, B. P., and Kastberger, G. (2000). Giant honeybees return to their nest sites. *Nature* 406, 475. doi: 10.1038/35020196
- Pot, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., and Kunin, W. E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends Ecol. Evol.* 25, 345–353. doi: 10.1016/j.tree.2010.01.007
- Pulungan, Z. N., Priawandiputra, W., Grass, I., Li, K., Robo, R. J., and Raffiudin, R. (2023). Tropical lowland rainforest conversion to rubber monoculture affects flight activity and pollen resources of the stingless bees *Tetragonula laeviceps* (Smith). *J. Entomol. Indones.* 20, 88–100. doi: 10.5994/jei
- Rattanawanee, A., Rod-im, P., and Duangphakdee, O. (2023). “Ecological services potential of *Apis dorsata* in Thailand,” in *Role of Giant Honeybees in Natural and Agricultural Ecosystems*. Ed. D. P. Abrol (CRC Press, Boca Raton, FL), 123–114.
- Reddy, C. C. (1980). Studies on the nesting behaviour of *Apis dorsata* F. *Intl. Conf. Apic. Trop. Climate* 2, 391–397.
- Robinson, W. S. (2012). Migrating giant honey bees (*Apis dorsata*) congregate annually at Stopover Site in Thailand. *PloS One* 7, e44976. doi: 10.1371/journal.pone.0044976
- Robinson, W. S. (2021). Surfing the sweet wave: migrating giant honey bees (Hymenoptera: Apidae: *Apis dorsata*) display spatial and temporal fidelity to annual stopover site in Thailand. *J. Insect Sci.* 21, 1–12. doi: 10.1093/jisesa/ieab037
- Rosmarlinasiah, M. D., Paembonan, S., and Yusuf, Y. (2015). Resource potential analysis of honey bee feed *Apis dorsata* in Mountain Timanggo Kolaka. *Int. J. Sci. Technol. Res.* 4, 313–318.
- Ruttner, F. (1988). *Biogeography and Taxonomy of Honeybees* (Berlin: Springer-Verlag). doi: 10.1007/978-3-642-72649-1
- Saepudin, R. (2014). Sustainability analysis and the effect of honeybee-coffee plantation integration model on improving the honey and coffee bean product. *Jurnal Ilmiah Ilmu-Ilmu Peternakan* 17, 1–9. doi: 10.22437/jiip.v17i1.2254
- Sajjad, A., Ali, M., and Saeed, S. (2017). Yearlong association of *Apis dorsata* and *Apis florea* with flowering plants: planted forest vs. Agric. lands. *Sociobiol.* 64, 18–25. doi: 10.13102/sociobiology.v64i1.995
- Sakagami, S. F., Matsumura, T., and Ito, K. (1980). *Apis laboriosa* in Himalaya, the little-known world largest honeybee (Hymenoptera: Apidae). *Insecta Matsumurana* 19, 47–77.
- Sakai, S., Momose, K., Yumoto, T., Nagamitsu, T., Nagamasu, H., Hamid, A. A., et al. (1999). Plant reproductive phenology over four years including an episode of general flowering in a lowland dipterocarp forest, Sarawak, Malaysia. *Am. J. Bot.* 86, 1414–1436. doi: 10.2307/2656924
- Sari, D. A., and Putra, R. E. (2015). Kajian karakter bunga *Coffea arabica* L. terkait dengan kemungkinan aplikasi lebah madu lokal sebagai agen penyerbuk. *Jurnal Matematika Sains* 20, 1–5.
- Schouten, C., Lloyd, D., Ansharyani, I., Salminah, M., Somerville, D., and Stimpson, K. (2020). The role of honey hunting in supporting subsistence livelihoods in Sumbawa, Indonesia. *Geogr. Res.* 58, 64–76. doi: 10.1111/1745-5871.12380
- Shannon, C. E. (1948). A mathematical theory of communication. *Bell Syst. Tech. J.* 27, 379–423. doi: 10.1002/bltj.1948.27.issue-3
- Shwetha, B. V., Neethu, T., Bharanth Kumar, A. K., and Bhat, N. S. (2023). “Distribution and nest site preference of *Apis dorsata* Fabricius,” in *Role of Giant Honeybees in Natural and Agricultural Ecosystems*. Ed. D. P. Abrol (CRC Press, Boca Raton, FL), 158–169.
- Silberbauer-Gottsberger, (1990). Pollination and evolution in palms. *Phyton* 30, 213–233.
- Singh, R. P., Singh, A. K., and Singh, R. P. (2007). The effect of the availability of bee forage plants and environmental conditions on the nesting of *Apis dorsata* Fabr. *J. Apic. Res.* 46, 276–281. doi: 10.1080/00218839.2007.11101408
- Somanathan, H., Warrant, E. J., Borges, R. M., Wallén, R., and Kelber, A. (2009). Resolution and sensitivity of the eyes of the Asian honeybees *Apis florea*, *Apis cerana* and *Apis dorsata*. *J. Exp. Biol.* 212, 2448–2453. doi: 10.1242/jeb.031484
- Stewart, A. B., Sritongchuay, T., Teartitup, P., Kaewsomboon, S., and Bumrungsri, S. (2018). Habitat and landscape factors influence pollinators in a tropical megacity, Bangkok, Thailand. *PeerJ* 6, e5335. doi: 10.7717/peerj.5335
- Stockmarr, J. (1971). Tablets with spores used in absolute pollen analysis. *Pollen Spores* 13, 615–621.
- Suwananpong, G., Maksong, S., Yemor, T., Junsuri, N., and Benbow, M. E. (2013). Three species of native Thai honey bees exploit overlapping pollen resources: Identification of bee flora from pollen loads and midguts from *Apis cerana*, *A. dorsata* and *A. florea*. *J. Apic. Res.* 52, 196–201. doi: 10.3896/IBRA.1.52.5.05
- Sze, J. S., Jefferson, and Lee, J. S. H. (2019). Evaluating the social and environmental factors behind the 2015 extreme fire event in Sumatra, Indonesia *Environ. Res. Lett.* 14, 015001. doi: 10.1088/1748-9326/aac1e1d
- Thapa, R. (2001). The Himalayan giant honey bee and its role in ecotourism development in Nepal. *Bee World* 82, 139–141. doi: 10.1080/0005772X.2001.11099516
- Wiryo, Lukman, A. H., and Nurliana, S. (2022). The species diversity and composition of seedlings for degraded land rehabilitation in different phytogeographical regions in Indonesia. *Biodiversitas* 23, 5771–5781. doi: 10.13057/biodiv/d231130
- Wongsiri, S., Thapa, R., Oldroyd, B. P., and Burgett, D. M. (1996). A magic bee tree. Home to *Apis dorsata* Fab. *Am. Bee J.* 136, 796–799.
- Young, A. M., Kodabalagi, S., Brockmann, A., and Dyer, F. C. (2021a). A hard day’s night: Patterns in the diurnal and nocturnal foraging behavior of *Apis dorsata* across lunar cycles and seasons. *PloS One* 16, e0258604. doi: 10.1371/journal.pone.0258604
- Young, A. M., Kohl, P. L., Rutschmann, B., Steffen-Dewenter, I., Brockmann, A., and Dyer, F. C. (2021b). Temporal and spatial foraging pattern of three Asian honey bee species in Bangalore. *India. Apidologie* 52, 503–523. doi: 10.1007/s13592-020-00839-1
- Zahara, I., Fahri, F., Lamerlabel, J. S., Qashiratutaraqi, Q., Juliandi, B., and Raffiudin, R. (2022). Landmark-Based Geometric Morphometric of *Apis dorsata* and *A. d. binghami* Wing Venation in Indonesian Archipelagos. *HAYATI J. Biosci.* 29, 658–668. doi: 10.4308/hjb.29.5.658-668