

Seasonal foraging gaps and floral resource enhancement opportunities for *Apis cerana* in a tropical conservation forest

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Abstract. Wulandari I, Husodo T, Kusmoro J, Megantara EN, Shanida SS, Amalia CA, Azzahra HR. 2025. Seasonal foraging gaps and floral resource enhancement opportunities for *Apis cerana* in a tropical conservation forest. *Biodiversitas* 26: 4201-4219. The Asiatic honey bee (*Apis cerana*) relies on pollen and nectar from flowering plants to sustain its colonies. When floral resources are limited, colonies may abscond, which threatens the livelihoods of beekeepers in the Ir. H. Djuanda Forest Park, West Java, Indonesia. Ensuring continuous forage availability is therefore essential for sustainable *A. cerana* management. This study aimed to (i) identify the food sources of *A. cerana*, both are based on pollen and flowering records, (ii) document the flowering period, and (iii) recommendations for forage enrichment in Ir. H. Djuanda Forest Park. Pollen trapping, quadrat, and direct observation were conducted within a 1 km radius of apiaries in Batu Garok, Deer Enclosure, and Maribaya. A total of 279 species were documented, consisting of 71 pollen plants and 252 flowering plants. The dominant floral families recorded were Asteraceae, Fabaceae, and Euphorbiaceae. The flowering plants diversity peaked between December and May, with 188-216 species (approximately 70-85% of the annual total) recorded during this period. In contrast, a critical floral gap occurred between June and November, when only 50-118 species (around 20-50% of the annual total) were in bloom. This seasonal gap restricts foraging opportunities and increases the risk of colony absconding. To mitigate this, 30 year-round flowering species are recommended for enrichment planting. Among the recorded species, red calliandra (*Calliandra calothyrsus*) and Mexican sunflower (*Tithonia diversifolia*) were dominant year-round forage plants, consistently supplied pollen and nectar, although both are invasive species. Non-invasive year-round species are also recommended to enrich forage availability during the gap months; among them are billygoat weed (*Ageratum conyzoides*) and hairy beggarticks (*Bidens pilosa*). These results highlight the value of implementing targeted habitat enrichment to help bridge seasonal gaps in floral resources. Such efforts can contribute to greater colony stability, support higher honey yields, and enhance pollination services within tropical conservation forests.

Keywords: Apiary, blooming, Djuanda, pollen trapping

INTRODUCTION

Foraging honeybees actively collect pollen and nectar from a much-diversified plant species to ensure the balance of biological nutrients and carbohydrates (Filipiak et al. 2017). Pollen is the primary source of minerals, protein, vitamins, sterols, and lipids for larval development (Descamps et al. 2021). Pollens are mixed with nectar and honey to make up bee bread for feeding adults and larvae, while nectar is converted into honey, the primary source of energy (Wright et al. 2018). In tropical areas, honeybees remain active and forage throughout the year; however, the flowering period is primarily affected by seasonal patterns. These seasonal patterns, in turn, have a direct impact on both the population density and the overall vitality of honeybee colonies (Piolletti et al. 2024).

Developing a floral calendar that indicates the timing of flowering, as well as the quantity and quality of pollen and nectar, would be useful information to Indonesian beekeepers. This would enable beekeepers to identify optimal harvesting periods, ensure their bees have

sufficient food resources to survive losses, and maximize yields during nectar flows (Schouten et al. 2019). Providing adequate floral resources is essential for sustainable habitat management targeting wild bees (Sutter et al. 2017). Small-scale farming heavily relies on the surrounding area and all biotic and abiotic interactions related to the crops (Sawe et al. 2020; Timberlake et al. 2022). Biotic interactions play an important role in these farms, especially insect interactions (Pywell et al. 2015). In Nepal, beekeeping and honey production with the native bee species *Apis cerana* (Fabricius, 1793) is a sustainable livelihood option for rural people in the Hindukush Himalayan countries (Partap et al. 2017). Knowledge of bees' biology and ecological behavior is essential in apiculture, as it helps to understand the associated problems and management (Aryal 2019).

One of the Indonesian beekeepers can be found in the Ir. H. Djuanda Forest Park, West Java and its surroundings (Nuriyah et al. 2021a). Previous studies have been conducted regarding the habitat of *A. cerana* as an apiary area in the Ir. H. Djuanda Forest Park (Kviesis et al. 2020; Nuriyah et al. 2021a, b; Husodo et al. 2024). Kviesis et al.

(2020) studied temperature and weight monitoring of the *A. cerana* colony using the Smart Apiculture Management Services (SAMS) in the Maribaya Apiary. They found that temperature and weight monitoring can be utilized for remote monitoring of bee colonies. Nuriyah et al. (2021a) identified 70 pollen plants of 36 families. Based on the vegetation (Nuriyah et al. 2021b), pine (*Pinus merkusii*) and red calliandra (*Calliandra calothyrsus*) are the dominant plants that have the potential as food sources for *A. cerana* in the Ir. H. Djuanda Forest Park. Previous study revealed a six-month flowering calendar and 41 plant pollens used as food sources for *A. cerana* (Husodo et al. 2024). They showed that food availability was limited at certain times. In Indonesia, several studies have been conducted on the food source of *A. cerana*. Some dominant plants flower during the honey harvest season in West Sumatra (Jasmi et al. 2020) and South Sulawesi (Hikmah et al. 2021). Schouten et al. (2019) studied the management of beekeeping in Java, Bali, Nusa Penida, and Sumbawa. However, the seasonal availability and flowering duration of *A. cerana* throughout the year is still understudied.

Regarding the introduction, the objectives of this study were to (i) determine the food sources of *A. cerana* both based on the presence of pollen and flowering in the Ir. H. Djuanda Forest Park, (ii) the flowering period of food sources, and (iii) recommendations for food source enrichment in the Ir. H. Djuanda Forest Park. This study aims to map the flowering period and availability of food sources, illustrating periods of scarcity and abundance throughout the year. This study is also expected to provide information on suitable times for honey harvesting and recommendations for plant enrichment in periods of food source scarcity. This study is also expected to provide basic information on plant composition as a determinant of honey quality. Different bee locations are influenced by various plants, which serve as nectar sources and are used to produce honey. Therefore, this affects the quality of honey, particularly its chemical composition (Nordin et al. 2018; Agus et al. 2021; Agussalim et al. 2021, et al. 2022; Agussalim and Agus 2022). Honey contains sugar as its main component, followed by protein (including amino acids and enzymes), ash (minerals), vitamins, organic acids, phenolics, and volatile compounds (Da Silva et al. 2016). Phenols have antibacterial and antioxidant properties (Parihar et al. 2020).

MATERIALS AND METHODS

Study area

Ir. H. Djuanda Forest Park (DFP) is located 107°30'00"E and 6°52'00"S, approximately 7 km from downtown Bandung District, West Java, Indonesia (Figure 1). The Forest Park is located in the Cikapundung Sub-watershed and the Citarum watershed, stretching from *Curug* (Waterfall) Dago, Dago Pakar, and *Curug* Maribaya (Nuriyah et al. 2021a). DFP is located in the Bandung District (Ciburial Village) and West Bandung District (Mekarwangi Village, Cibodas Village, Langensari Village, and Wangunharja Village), as well as in Bandung City

(Dago Village) (Ervinia et al. 2020). DFP has an area of 528.39 hectares, with a land cover dominated by plantation forests of 475.15 hectares. Other land cover types include secondary forests covering an area of 19.65 hectares, shrubs covering an area of 29.55 hectares, ponds covering an area of 1.18 hectares, and open areas of 2.83 hectares.

The study was conducted in three *A. cerana* apiaries within the DFP, specifically at Batu Garok (Bandung District), Deer Enclosure (West Bandung District), and Maribaya/Madu Maribaya Legend Bee (West Bandung District) (Figure 1). The apiary activities must be concentrated on sites that generate much nectar, pollen, and water (Hikmah et al. 2021). Dyer and Seeley's (1991) research shows that for *A. cerana*, half of the studies indicated foraging sites within 196 m of the hive, and 95% indicated foraging within 1 km of the hive. Therefore, we focused on a radius of 1 km from each apiary as foraging areas of *A. cerana*. Batu Garok is dominated by dry fields located outside the Ir. H. Djuanda Forest Park area, which covers approximately 131.29 hectares. In contrast, the area within the DFP comprises plantation forests, covering 92.90 hectares. Deer Enclosure is also dominated by dry fields, covering 139.68 ha outside the area and plantations, covering 123.34 ha inside the area, and Maribaya is dominated by dry fields covering 105.22 ha and plantations, covering 127.42 ha (Table 1).

Procedures

Pollen trapping

Pollen trapping was collected in August 2021 (dry season) (Husodo et al. 2024) and June 2024 (wet season) in the beekeeping sites, such as Batu Garok, Deer Enclosure, and Maribaya. Pollen trapping was conducted to determine the plants used as food for *A. cerana* in a landscape. According to Topitzhofer et al. (2021), this method can be used to describe the plants utilized by honey bees in the landscape as a first step in determining the quantity, quality, and taxa of flowering plant species. Pollen traps are designed to release corbicular pollen from the legs of honey bees (Komosinska-Vassev 2015; Kaplan et al. 2016; Judd et al. 2020) that have returned from foraging and re-entered the hive (Judd et al. 2020). This method is more efficient when many samples are collected by trapping pollen pellets from honeybees at the entrance to the hive (Topitzhofer et al. 2021). Previous studies have shown that pollen traps encourage honeybees to collect more pollen, thereby enhancing pollination efficiency in crops and vegetation (Gemedeta et al. 2018).

Colonies were selected based on forager activity, which was quantified by counting the number of bees entering the hive during a two-minute period. Counts were performed three times per colony at 7:00 to 10:00 AM and 2:00 to 4:00 PM, which are effective times for bee pollination (Stabentheiner and Kovac 2016). Colonies with the highest forager numbers were chosen for pollen trapping. The hives should have wooden fittings in good condition, preferably without additional entrances and curved lids. We used nests with few alternative entrances, as this increases the likelihood that foragers will reorient themselves to the trap entrance.

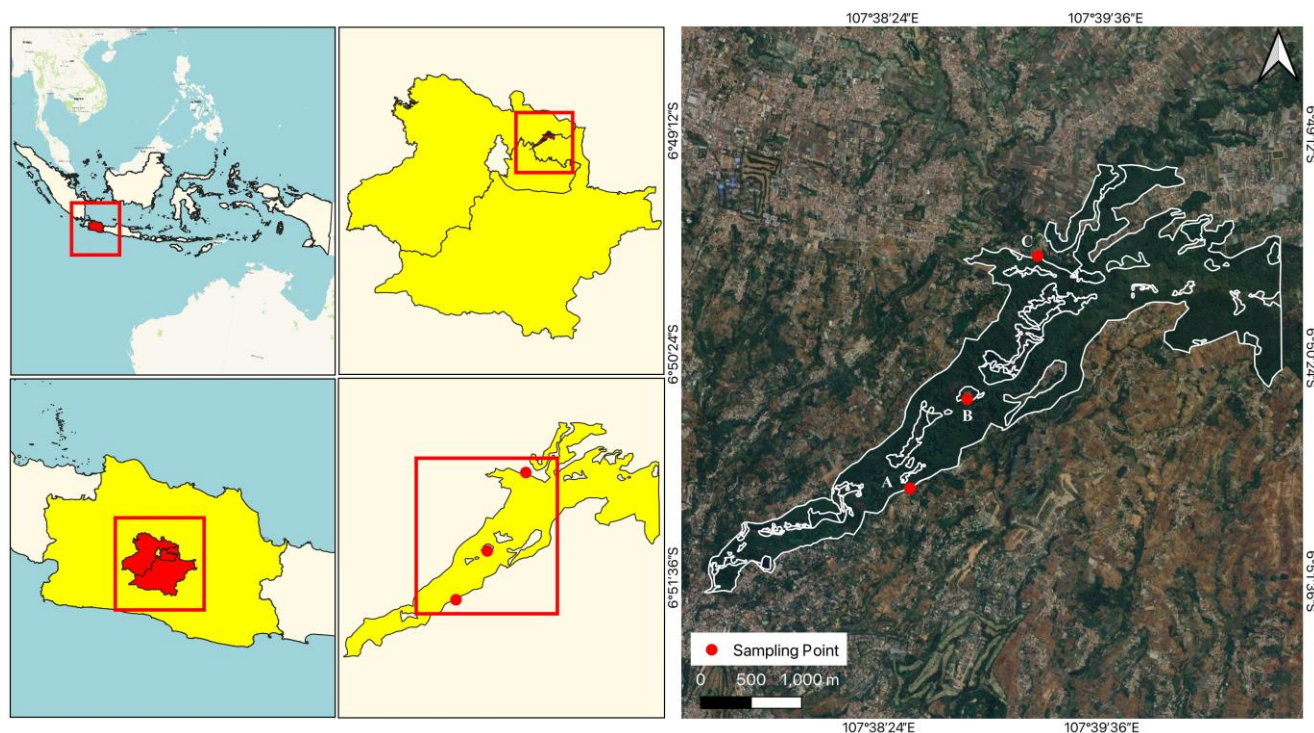


Figure 1. The study area in Ir. H. Djuanda Forest Park, West Java, Indonesia. A. Batu Garok (6°51'24.55"S, 107°37'44.93"E), B. Deer Enclosure (6°50'37.33"S, 107°38'59.88"E), C. Maribaya/Madu Maribaya Legend Bee (6°50'7.25"S, 107°39'30.23"E). Source: Primary Data (2021)

Table 1. Land cover types in the foraging area, Ir. H. Djuanda Forest Park, West Java, Indonesia

Land cover types	Areas (ha)		
	Batu Garok	Deer Enclosure	Maribaya
Inside DFP			
Open Areas	-	-	0.42
Plantation Forest	92.90	123.34	127.42
Secondary Forest	8.26	9.62	8.15
Shrubs	4.40	8.68	10.72
Outside DFP			
Ponds	-	0.17	-
Buildings	0.37	-	2.21
Settlements	39.24	15.05	18.60
Horticulture	24.60	13.00	28.40
Wet Fields	8.69	3.83	-
Shrubs	5.26	0.93	13.37
Dry Fields	131.29	139.68	105.22
Total	315.06	314.36	314.60

Source: Primary Data (2021)

Pollen trap installation and sampling were referred to as Topitzhofer et al. (2021). Traps were installed in the evening when honey bee activity was low and all alternative entrances were sealed with adhesive tape to ensure bees passed through the trap entrance. The traps were left in place for 24 hours prior to sampling to allow the colonies to habituate. Following Dimou et al. (2006), pollen collection was carried out for three consecutive days (72 hours) every nine days per colony. After each collection, the entrance holes in the pollen trap were

removed for nine days to allow the honeybees to re-collect pollen for the hive, without removing the entire trap. Sampling was then repeated twice by reinstalling the entrance holes. In total, nine colonies (three per site) were used for pollen trapping and each colony was sampled three times, resulting in 27 pollen samples.

After collection, the corbicular pollen was removed from the trap container, placed in a plastic bag (ziplock), and stored in the storage box to avoid damage and breakage. The samples were cleaned of bee body parts and nest debris, such as wings, skins, etc. Disposable gloves were used during handling, with new gloves and separate equipment for each sample to avoid contamination. Each sample was labeled with the date, colony location, and sampling time.

Acetolysis

The acetolysis method is the standard method in palynological preparation. This method is also indispensable for illustrating pollen grains by light microscopy. Stained pollen grains cover the visuals, making it difficult to provide an overview of the pollen grains. The acetolysis process removes the cellular wall and the intine and destroys the aperture membrane. Additionally, cleaning the surface of the pollen grain and coloring it can make it easier for researchers to observe all the details of the pollen grain wall (Erdtman 1960). The Acetolysis method combines chlorination and acetylation procedures (Hesse et al. 2009).

Chlorination stage. Pollen was placed into a centrifugation tube, which was then added to 98% glacial acetic acid (AAG) and 3-4 drops of HCl. Then, stir the mixture using a glass rod to ensure it is mixed evenly. The pollen was heated using a water bath for three minutes. After heating, the pollen was centrifuged at 2,000-3,000 rpm for 10 minutes. The supernatant was removed to prevent waste of the pollen deposits, and the residue was then washed with distilled water (approximately 5-10 mL, adjusted to the centrifuge tube volume). The sample was centrifuged again at 2,000-3,000 rpm for 2 minutes. Washing was carried out three times to remove AAG.

Acetylation Stage. A mixture of 98% AAG and sulfuric acid, in a 9:1 ratio, was dropped into the tube. After that, it was heated to 100°C for four minutes. The pollen was centrifuged at 2,000-3,000 rpm for 10 minutes. The supernatant was removed slowly to prevent wasting the pollen deposits, and the residue was then washed with distilled water. The sample was centrifuged again at 2,000-3,000 rpm for 2 minutes. Washing was performed three times to remove the mixture of AAG and sulfuric acid. After the acetolysis method, the pollen samples were stored in a wet preservation solution. The samples were stored in a 20-cc vial and added to distilled water. Halbritter et al. (2018) state that dry and fresh pollen must be hydrated with water to obtain a good-quality pollen grain. This condition ensures that the pollen grains are not damaged or contaminated with fungi. Each vial was labelled and stored in the refrigerator until observation in a month. For observation, a wet sample was taken to observe and identify pollen. Then, 1-2 drops were placed on a glass object, and one drop of glycerin was added. Halbritter et al. (2018) stated it should be observed as soon as possible after being given glycerin because the pollen grains will expand within a few days or weeks. Then, glycerin jelly was applied to the edges of the cover glass to prevent it from shifting. After that, the microscope slide was dried on a hot plate and labelled.

Flowering observation

Flowering observation were carried out every two weeks from May 2024 to April 2025. This observation aimed to identify potential floral sources for *A. cerana* on flowering plants in the DFP. Each observation lasted for two consecutive days (typically during weekends), resulting in a total of 4-6 observation days per month. Two observers walked along three predetermined transect within the foraging area of *A. cerana*, with a total length of approximately 13.24 km (Maribaya transect: 2.5 km; Deer Enclosure transect: 4.5 km; and Batu Garok transect: 6.24 km). The transect route was kept consistent across all sampling periods to ensure comparability. Along the walk, all plant species that were flowering were recorded. For tall or hard-to-reach plants, observations were made using binoculars and cameras (Jasmi 2017). Plant species were identified using the Flora of Jawa guidebook (van Steenis et al. 2010). The required parameters included flowering plants, whether the plant was cultivated or wild, flowering duration, and habitus type (tree, bush, shrub, herbaceous plant, or liana). Each species was recorded as “flowering”

if at least one individual was observed producing flowers during the observation; the number of flowers and flower buds was not quantified.

Floristic study

Sampling was conducted at four cardinal directions from each bee-keeping site (Figure 2) in May 2024. Vegetation species inventories and analyses were performed using line transects according to the land cover type in the sampling area. Vegetation data were collected through field surveys that involved identifying plant species. Sampling was carried out using the quadrat technique to assess vegetation structure, species composition, and density. Along each 100 m transect, five main plots of 20x20 m² were established at regular intervals (every 20 m). Within each main plot were subdivided into smaller units based on the growth level: (i) Seedling-size plots (2x2 m²), with a height of less than 1.5 m and including understory, shrub, and herbaceous plants, as well as lianas, epiphytes, pandanus, and palms; (ii) Sapling-size plots (5x5 m²), with a height greater than 1.5 m and a stem diameter less than 10 cm; (iii) Pole-size plots (10x10 m²), with a stem diameter between 10 and 19.9 cm; (iv) Tree-size plots (20x20 m²), with a trunk diameter of at least 20 cm. Thus, each transect contained five main plots and each site had four transects (on ein each cardinal direction), resulting in a total of 20 main plots per site.

Data analysis

Data obtained through the quadrat method were tabulated using Microsoft Excel, including the species diversity of trees, poles, and saplings. Species diversity was analyzed using the Relative Frequency (RF), Relative Density (RD), Relative Dominance (RC), Important Value Index (IVI), and Shannon-Wiener's diversity index (H') (Dharma et al. 2021).

$$\text{Frequency (F)} = \frac{\text{The number of plots which is found a species}}{\text{The total number of plots}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of species}}{\text{The total number of all species density}} \times 100\%$$

$$\text{Density (D)} = \frac{\text{All number of individual species}}{\text{The total width of plots}}$$

$$\text{Relative Density (RD)} = \frac{\text{Density of a species}}{\text{The total number of all species density}} \times 100\%$$

$$\text{Dominance} = \frac{\text{The total of basal area of a species}}{\text{The total width of plots}}$$

$$\text{Relative Dominance (RC)} = \frac{\text{Dominance of a species}}{\text{The total dominance of all species}} \times 100\%$$

$$\text{IVI} = \text{RF} + \text{RD} + \text{RC}$$

$$H' = -\sum \left(\frac{ni}{N} \right) \ln \left(\frac{ni}{N} \right)$$

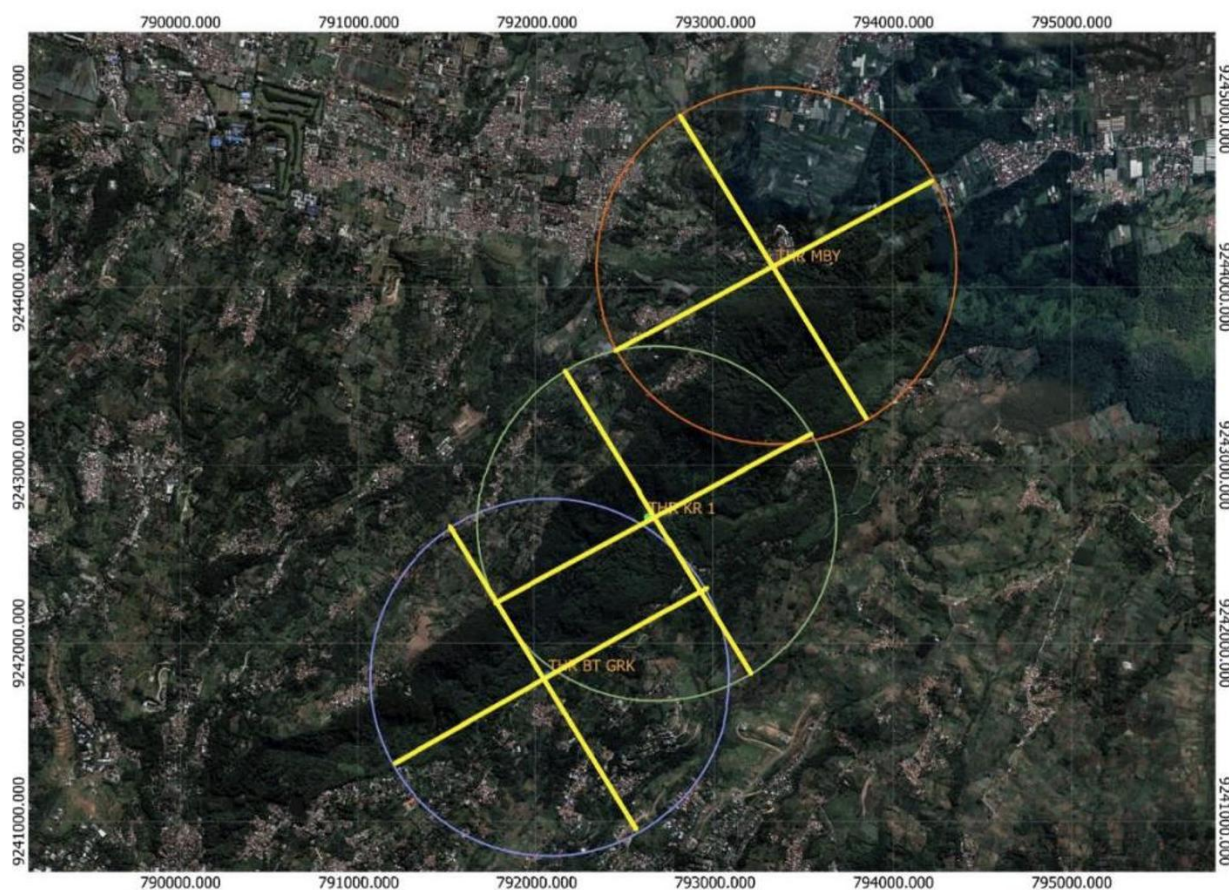


Figure 2. Transect sampling of vegetation in the Ir. H. Djuanda Forest Park, West Java, Indonesia

The IVI is the sum of the RF, RD, and RC, ranging from 0 to 300. p is the proportion of individuals of a particular plant species (n/N), divided by the total number of individuals (N). s is the number of species, Σ is the sum of the calculations, and \ln is the natural logarithm (Chapungu et al. 2020). Species diversity is categorized as high ($H' > 3$), moderate ($1 \leq H' \leq 3$), or low ($H' < 1$) (Odum 1993). The three species with the highest scores are shown in the table, which is organized by apiary and growth level (tree, pole, sapling, and seedling).

Data obtained from pollen trapping was tabulated in Microsoft Excel and explained qualitatively. Several pollen identification guidelines, such as those of Erdtman (1969) and Faegri and Iversen (1989), were used. Species identification was conducted based on pollen morphology, including shape, size, and type of ornamentation. The pollen data represent a list of plant species utilized by *A. cerana* as forage sources during the sampling period.

The flowering observation data were analyzed descriptively and qualitatively. Information related to flowering was displayed in tables, supplemented with bar charts that illustrated the flowering period over a 12-month period. Flowering species were categorized by apiary to determine the number of flowering plants within each apiary. A table showing the presence of pollen alongside

the flowering table illustrates the presence of pollen and flowering plants in each species per apiary.

Data on species obtained from flowering observations, floristic analysis, and pollen studies were cross-checked to determine which pollen plants were found inside and outside the foraging area, as well as which plants were found to be flowering throughout the year. These findings were supported by pollen data. Several species were selected as recommendations for food source enrichment in the DFP based on the following considerations: (i) species that flower throughout the year, and (ii) the presence of pollen plants.

RESULTS AND DISCUSSION

A total of 71 pollen species of 42 families was recorded (Table 5), with dominance from the Euphorbiaceae and Fabaceae families, each comprising seven species. This indicates that 71 plants were selected as nutritional sources for *A. cerana*. Based on their habitats, the most pollen was obtained from 29 tree species, including the orange (*Citrus sinensis*), water apple (*Syzygium aqueum*), barrelier's woodsorrel (*Oxalis barrelieri*), and hairy fig (*Ficus hispida*). The importance of trees for honey bees is well-known (Donkersley 2019), as they are often among the

early-flowering species (Malagnini et al. 2022). In comparison to the other species, the European honey bees (*Apis mellifera* (Linnaeus, 1758)) tend to forage on the kapok tree (*Ceiba pentandra*), rubber tree (*Hevea brasiliensis*), rambutan (*Nephelium lappaceum*), and red calliandra (*C. calothyrsus*) (Purwanto et al. 2024). The highest number of plant pollen was detected at Batu Garok apiary (54 species), followed by Maribaya and Deer Enclosure.

Throughout the year, 252 species from 82 families were recorded flowering at DFP (Table 3), with varying flowering durations. The Asteraceae family was found to have the most species, with 25, followed by the Fabaceae family with 20 species and the Euphorbiaceae family with 14 species. Herbaceous plants dominate flowering plants compared to other habitus. The most flowering plants were found in Batu Garok (171 species), followed by Maribaya and Deer Enclosure.

Of the 279 species, 26 were detected only by pollen presence (Table 3), not by floristic analysis or flowering observation. Some of these species were crops, including corn (*Zea mays*), chili pepper (*Capsicum annum*), and black nightshade (*Solanum nigrum*). Other species include wild cherry (*Antidesma bunius*), Siamese cassia (*Cassia siamea*), and black ebony (*Diospyros celebica*), which are wild plants. These plants were found outside the estimated foraging area, suggesting that *A. cerana* foraged more than 1 km from the apiaries in the DFP. Given their preference for pollinated plants outside the foraging area compared to nearby flowering plants, these 26 species could enrich the DFP's food sources, thereby minimizing absconding and maintaining the cultivation of *A. cerana* over the next few years.

Of the 26 species, 11 are trees, 10 are herbaceous plants, three are shrubs, and two are bushes. No liana plants were found among these pollen plants. Seventeen of the 26 species are wild plants, and the rest are cultivated. Most of these pollen plants were found in Batu Garok (21 species), followed by Maribaya and Deer Enclosure (Figure 3). The presence of pollen from cultivated plants suggests that *A. cerana* seeks out food sources on cultivated land, including agricultural fields and home gardens. These sources include *Z. mays*, *A. bunius*, *C. annum*, and *S. nigrum*. This demonstrates a pollination service on crop land, which

supports optimizing agricultural productivity. Nevertheless, pesticide application in farming areas remains a critical concern that needs to be managed to ensure the long-term sustainability of pollination services. The detection of pollen from wild plant species indicates that pollination activities take place within the DFP, thereby supporting the conservation of the habitat of *A. cerana*.

During the dry season, the diversity of flowering plants tends to be high, from December to May, with a range of 70-85% (188-216 species). In contrast, the wet season from June to November results in a drastic decrease, ranging from 20-50% (50-118 species) (Figure 4). The high diversity of flowering plants from December to May may indicate a high abundance of food during that period, which in turn allows for the harvesting of honey. Despite reduced food availability due to harvesting, *A. cerana* can still forage with abundant food sources. In comparison to the beekeeping in South Sulawesi, harvesting of honey is usually carried out in September-October when the flowering season of coffee (*Coffea* sp.) and mango (*Mangifera indica*) and January-February, during the flowering season of *C. calothyrsus*, avocado (*Persea americana*), red dadap (*Erythrina crista-galli*), gamal (*Gliricidia sepium*), teak (*Tectona grandis*), and melochia (*Melochia umbellata*) (Hikmah et al. 2021).

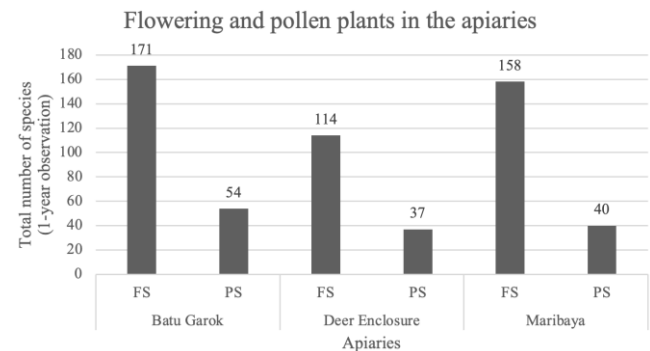


Figure 3. Total number of Flowering Species (FS) and Pollen Species (PS) recorded in each apiary during one year of observation (May 2024-April 2025). Source: Husodo et al. (2024); Primary Data (2024-2025)

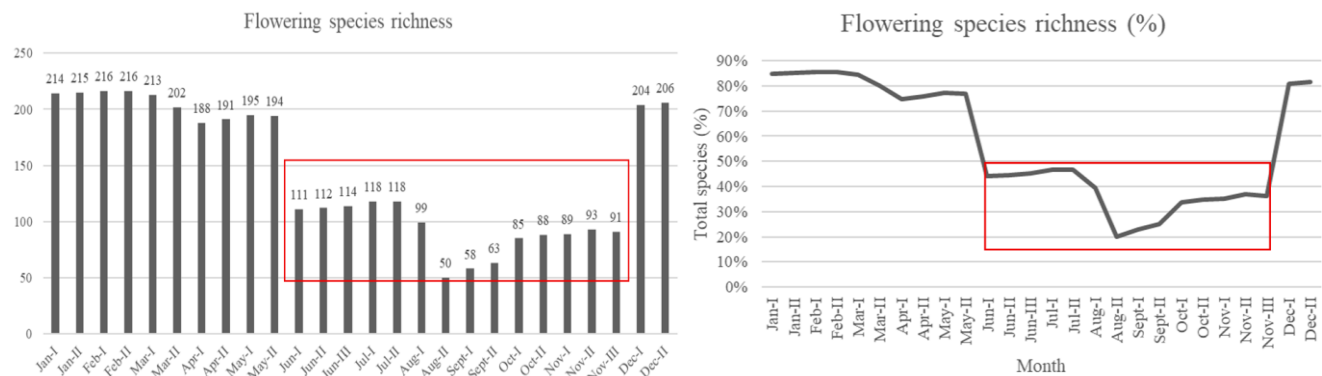


Figure 4. Flowering species richness all year round. Low food source. Source: Husodo et al. (2024), Primary Data (2024-2025)

The diversity of plants that serve as forage resources for bees is vast and influenced by factors such as flower shapes, abundance, and the quality and quantity of nectar and pollen (Venjakob et al. 2022; da Silva Alencar et al. 2023). These differences can impact honey bee foraging behavior, colony health, overall honey production, and its quality (Somme et al. 2015; Kavitha and Reddy 2019). For example, nectar-rich flowers attract more foraging bees and often result in higher honey yields (Nicolson 2022; Nicolson et al. 2022). Some plant species produce pollen that is richer in proteins, fats, and other nutrients essential for bee larval development than others (Venjakob et al. 2022). This intricate relationship underscores the importance of preserving diverse floral resources to support honey bee health, enhance their pollination efficiency, and optimize honey production.

The low diversity of flowering plants from June to November could indicate low food resources. Harvesting during this time increases the risk of absconding due to the loss of food storage. Even though honeybees actively collect pollen year-round in tropical areas, the worker bee population decreases during the rainy season due to increased infertile egg laying (Torres et al. 2015). The collected pollen is then stored to feed the colony until the melliferous season begins again (Amakpe et al. 2024). The lack of diversity can negatively impact bee populations, as they may struggle to find sufficient food sources later in the season. High plant diversity prolongs the foraging season for honey bees (Heller et al. 2019).

31 species flower year-round during 47-52 weeks (90%-100%) in DFP (Table 3). Of these, seven species also contributed pollen, as confirmed through microscopic analysis, including billygoat weed (*Ageratum conyzoides*), hairy beggarticks (*Bidens pilosa*), spiny amaranth (*Amaranthus spinosus*), sessile joyweed (*Alternanthera sessilis*), yellow peanut plant (*Arachis pintoi*), *C. calothyrsus*, and *T. diversifolia*. These suggest that *A. cerana* selects them as food sources. These species are important because they provide continuous pollen and nectar resources, ensuring a baseline food supply for *A. cerana* colonies throughout the year. This pattern is comparable to findings in West Sumatra by Jasmi et al. (2020), where coconut (*Cocos nucifera*) and areca palm (*Chrysalidocarpus lutescens*) have become a continuous source of nectar and pollen for bees, as they flower throughout the year. Planting flowers all year round will ensure food supply for the colonies (Jasmi et al. 2020). Year-round flowering species can maintain colony survival during the gap month. In contrast, 153 species flowered only for 21-46 weeks (40-89%) and 68 species flowered briefly for just 4-20 weeks (0-39%). These shorter flowering periods contribute to seasonal fluctuations in resource availability.

Based on the diversity index, Batu Garok generally has a moderate level of diversity (Figure 5). It has the highest index compared to other apiaries at the tree, pole, and sapling levels, with a moderate diversity index. However, Batu Garok has the lowest seedling diversity index compared to other apiaries. Batu Garok is dominated by *P. merkusii*, Indian pulai (*Alstonia scholaris*), blue marble tree

(*Elaeocarpus angustifolius*), umbrella tree (*Maesopsis eminii*), and *C. calothyrsus*. Pollen was found in all these plants except *E. angustifolius* and *M. eminii*. This suggests that these two dominant plants were not selected as food sources, while *C. calothyrsus* is a plant that flowers year-round. Maribaya has a moderate number of flowering and pollen plants compared to other apiaries (Figure 3). Based on the diversity index, the diversity of trees, poles, saplings, and seedlings is all moderate (Figure 5). Maribaya has a lower diversity index than Deer Enclosure, especially at the pole level. Maribaya is dominated by *P. merkusii*, cinnamon (*Cinnamomum burmanni*), mara (*Macaranga tanarius*), and *C. calothyrsus*. Only *P. merkusii* and *C. calothyrsus* were found to have pollen as a food source. Similar to Batu Garok, only *C. calothyrsus* flowers year-round.

The Deer Enclosure has the fewest flowering and pollen plants compared to other apiaries (Figure 3). Based on the diversity index, the site exhibits moderate diversity; however, the diversity of trees and saplings is the lowest among the three sites, compared to Batu Garok and Maribaya (Figure 5). The Deer Enclosure is dominated by *P. merkusii*, East African mahogany (*Khaya anthotheca*), clove (*Syzygium aromaticum*), and *C. calothyrsus*. No pollen of *S. aromaticum* found, indicating that this dominant plant is not selected as a food source. Similar to Batu Garok and Maribaya, *C. calothyrsus* is the only plant that flowers year-round in the Deer Enclosure.

Pinus merkusii and *C. calothyrsus* were dominant in all apiaries. Both species were found to have pollen used as a food source. However, pine (*P. merkusii*) has a shorter flowering period (23%) than *C. calothyrsus*, which flowers throughout the year (100%) (Table 5). A prolonged flowering duration increases a plant's chance of pollination and thus likely improves plant performance (Trunschke and Stöcklin 2017). DFP has Mexican sunflower (*Tithonia diversifolia*), which flowers year-round (92%) and has pollen in all apiaries. It dominates in the Deer Enclosure and Maribaya. *C. calothyrsus* and *T. diversifolia* is an invasive species that is ecologically detrimental to the ecosystem. However, they can be relied upon as food sources for *A. cerana*, which is abundant and available throughout the year. Theisen-Jones and Bienefeld (2016), *A. cerana* has the ability to forage in extreme conditions. This honey bee can be cultivated without supplements if food resources are available year-round.

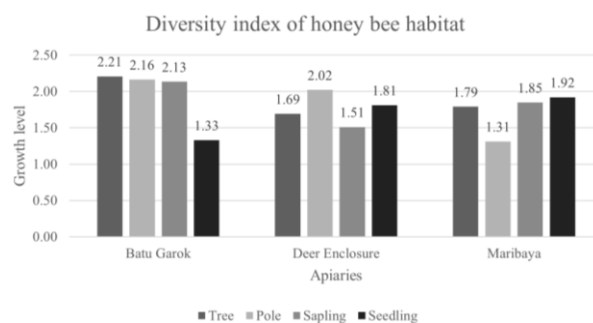


Figure 5. Diversity index of honey bee habitat based on growth level. Source: Primary Data (2024)

Based on microscopic observations, the pollen of *C. calothyrsus* is very large (>100 µm) with a polyad pollen type and a sub-oblate, porate ornamentation type. In contrast, the pollen of *T. diversifolia* is small (10-25 µm) with a monad pollen type and a spheroidal ornamentation type. According to the study by Husodo et al. (2024), *C. calothyrsus* is very large (>100 µm), while *T. diversifolia* is small (12.5 µm). Judging by its size, *A. cerana* carries fewer *C. calothyrsus* pollen loads than *T. diversifolia*. Considering that *A. cerana* prioritizes energy efficiency in foraging, pollen from the *T. diversifolia* is more promising for collecting food resources in a single foraging session.

This study recommends 30 plant species for enriching the forage plants of *A. cerana* in DFP and its surroundings (Table 2). These plants include both wild and cultivated species. These plants can be integrated into forest edges, along apiary paths, or in open gaps within a foraging radius of 1 km. By offering flowers consistently throughout the season, flower plantings can compensate for shortages of feeding resources in a landscape and thus support bees with differing phenologies. In annual flower plantings, this can be achieved by mixing annual and perennial plant species (Neumüller et al. 2021). However, *T. diversifolia* and *C. calothyrsus* should be excluded from these

recommendations because they are invasive and dominate bee habitats. Nevertheless, these species should be included in Table 2 as plants that flower year-round and produce pollen. A diverse range of flowering plants that bloom at different times throughout the year provides a continuous source of nectar and pollen for honey bees, preventing food shortages during critical periods (Williams et al. 2015). Therefore, fostering the growth and conservation of diverse, native flowering plants is fundamental to mitigating honey bee colony declines and ensuring the resilience of ecosystems that depend on pollination services (Mramba 2025). Conservation of flowering plants is critical not only for sustainable honey production but also for supporting pollinators and maintaining ecosystem health (Kammerer et al. 2016).

Pollen plants found outside the foraging area are prioritized for enriching food sources. However, floristic studies and flowering observations show this pollen plants are not found in the foraging area. Additionally, *A. cerana* Fabr. tends to choose these plants as food sources over other available flowering plants within the foraging area. Therefore, these considerations are used to prioritize planting these food plants.

Table 2. Recommendation of feed source enrichment

Family	Species	Common name	Habitus					WP	CP	Data type
			T	B	S	H	L			
Amaranthaceae	<i>Alternanthera sessilis</i>	Sessile Joyweed					+		Fl, Po	
	<i>Amaranthus spinosus</i>	Spiny Amaranth					+		Fl, Po	
Araceae	<i>Arum maculatum</i>	Cuckoo Pint					+		Po*	
Asteraceae	<i>Ageratum conyzoides</i>	Billygoat Weed					+		Fl, Po	
	<i>Bidens pilosa</i>	Hairy Beggarticks					+		Fl, Po	
	<i>Tithonia diversifolia</i> *	Mexican Sunflower			+		+		Fl, Po	
Caesalpiaceae	<i>Caesalpinia pulcherrima</i>	Peacock Flower	+				+		Po*	
Clusiaceae	<i>Calophyllum inophyllum</i>	Alexandrian Laurel	+				+		Po*	
Ebenaceae	<i>Diospyros celebica</i>	Black Ebony	+				+		Po*	
Euphorbiaceae	<i>Flueggea virosa</i>	White Berry Bush				+			Po*	
Fabaceae	<i>Arachis pintoii</i>	Yellow Peanut Plant					+		Fl, Po	
	<i>Calliandra calothyrsus</i> *	Calliandra				+			Fl, Po	
	<i>Cassia siamea</i>	Siamese Cassia	+					+	Po*	
Gramineae	<i>Trifolium repens</i>	Dutch Clover					+		Po*	
Magnoliaceae	<i>Michelia champaca</i>	Champaca	+					+	Po*	
Myrtaceae	<i>Syzygium</i> sp.	-	+					+	Po*	
Nyctaginaceae	<i>Pisonia aculeata</i>	Thorny Pisonia				+			Po*	
Phyllanthaceae	<i>Antidesma bunius</i>	Wild Cherry					+		Po*	
Poaceae	<i>Zea mays</i>	Corn					+		Po*	
Pteridaceae	<i>Pteridium</i> sp.	Bracken					+		Po*	
Rosaceae	<i>Prunus</i> sp.	Cherry	+					+	Po*	
	<i>Sanguisorba minor</i>	Garden Burnet	+					+	Po*	
Rubiaceae	<i>Gardenia jasminoides</i>	Kacapiring	+					+	Po*	
	<i>Haldina cordifolia</i>	Haldu					+		Po*	
Salicaceae	<i>Flacourtia rukam</i>	Rukam	+					+	Po*	
Solanaceae	<i>Capsicum annum</i>	Chili Pepper	+				+		Po*	
	<i>Physalis angulata</i>	Angular Winter Cherry			+		+		Po*	
	<i>Solanum nigrum</i>	Black Nightshade				+	+		Po*	
Urticaceae	<i>Urtica dioica</i>	Pulus					+		Po*	
	<i>Villebrunea rubescens</i>	Leaf That Licks				+	+		Po*	

Source: Primary Data (2024-2025), +: Presence, T: Tree, B: Bush, S: Shrub, H: Herbaceous, L: Liana, WP: Wild Plant, CP: Cultivated Plant, Fl: Year-round flowering (90%-100%), Po: Pollen, Po*: Pollen plants encountered in the outside of estimated foraging area, *: Key forage species

<i>Wedelia paludosa</i> DC.	Singapore Daisy		+		+	+	+	
<i>Youngia japonica</i> (L.) DC.	Oriental False Hawksbeard	+		+		+		
<i>Zinnia elegans</i> L.	Elegant Zinnia	+				+		
Balsaminaceae								
<i>Impatiens balsamina</i> L.	Garden Balsam	+				+		
<i>Impatiens walleriana</i> Hook.f.	Busy Lizzie	+		+		+		
Begoniaceae								
<i>Begonia cucullata</i> Willd.	Wax Begonia			+		+		
Bignoniaceae								
<i>Bignonia callistegioides</i> Cham.	Violet Trumpet Vine	+				+		
<i>Handroanthus chrysotrichus</i> (Mart. ex DC.) Mattos	Golden Trumpet Tree	+						
<i>Jacaranda mimosifolia</i> D.Don	Jacaranda					+		
<i>Kigelia africana</i> (Lam.) Benth.	African Sausage Tree	+	+	+	+	+		
<i>Pyrostegia venusta</i> (Ker Gawl.) Miers	Flame Vine					+		
<i>Spathodea campanulata</i> P.Beauv.*	African Tulip Tree	+	+	+	+	+	+	
<i>Tecoma stans</i> (L.) Juss. ex Kunth	Golden Bells	+						
Bixaceae								
<i>Cochlospermum regium</i> (Schrank) Pilg.	Yellow Cotton Tree	+						
Brassicaceae								
<i>Brassica oleracea</i> L.	Cabbage					+	+	
<i>Rorippa indica</i> L.	Indian Marshcress	+		+		+		
Cactaceae								
<i>Hylocereus lemairei</i> (Hook.) Britton & Rose	Red Dragon Fruit	+						
Caesalpinaceae								
<i>Caesalpinia pulcherrima</i> (L.) Sw.	Peacock Flower			+				
Campanulaceae								
<i>Hippobroma longiflora</i> (L.) G.Don	Star of Bethlehem	+		+				
Cannabaceae								
<i>Trema orientalis</i> (L.) Blume	Charcoal Tree	+	+	+	+	+	+	
Cannaceae								
<i>Canna indica</i> L.	Indian Shot	+				+		
Caricaceae								
<i>Carica papaya</i> L.	Papaya	+				+		
Chloranthaceae								
<i>Chloranthus elatior</i> Link	Barau-Barau					+		
Cleomaceae								
<i>Cleome rutidosperma</i> DC.	Fringed Spiderflower	+				+		
<i>Cleome spinosa</i> Jacq.	Spiny Spiderflower					+		
Clusiaceae								
<i>Calophyllum inophyllum</i> L.	Alexandrian Laurel			+			+	
Combretaceae								
<i>Terminalia catappa</i> L.	Sea Almond			+		+	+	+
Commelinaceae								
<i>Commelina benghalensis</i> L.*	Benghal Dayflower			+		+		
<i>Commelina communis</i> L.	Asiatic Dayflower	+		+				
<i>Tradescantia fluminensis</i> Vell.	Small Leaf Spiderwort	+		+				

<i>Tradescantia zebrina</i> Bosse	Silver Inch Plant	+		+	
Convolvulaceae					
<i>Ipomoea cairica</i> (L.) Sweet	Messina Creeper	+	+	+	
<i>Ipomoea obscura</i> (L.) Ker Gawl.	Obscure Morning Glory	+	+	+	
Costaceae					
<i>Costus afer</i> Ker Gawl.	Ginger Lily	+		+	
<i>Costus barbatus</i> Suess.	Red Tower Ginge	+	+		
<i>Hellenia speciosa</i> (J. Koenig)	Crepe Ginger		+		
Crassulaceae					
<i>Kalanchoe blossfeldiana</i> Poelln.	Christmas Kalanchoe			+	
Cucurbitaceae					
<i>Cucumis melo</i> L.	Melon			+	
<i>Momordica charantia</i> L.	Bitter Melon		+		
Cyperaceae					
<i>Cyperus kyllingia</i> Endl.	White-Flowered Kyllinga	+	+	+	
Dilleniaceae					
<i>Tetracera scandens</i> (L.) Merr.	Stone Leaf		+	+	
Ebenaceae					
<i>Diospyros celebica</i> Bakh.	Black Ebony		+		
Elaeocarpaceae					
<i>Elaeocarpus angustifolius</i> Blume*	Blue Marble Tree	+	+	+	
Ericaceae					
<i>Rhododendron</i> sp.	Azalea			+	
Euphorbiaceae					
<i>Acalypha paniculata</i> Miq.	Valia-Kuppameni	+			
<i>Cnidioscolus aconitifolius</i> (Mill.) I.M.Johnst.	Chaya	+		+	
<i>Codiaeum variegatum</i> (L.) Rumph. ex A.Juss.	Variiegated Croton	+		+	
<i>Euphorbia heterophylla</i> L.	Hairy Spurge	+		+	
<i>Euphorbia hirta</i> L.	Asthma-Plant	+		+	
<i>Euphorbia hypericifolia</i> L.	Graceful Spurge	+			
<i>Euphorbia milii</i> Des Moul.	Crown of Thorn	+		+	
<i>Euphorbia pulcherrima</i> Willd. ex Klotzsch	Poinsettia		+	+	
<i>Flueggea virosa</i> (Roxb. ex Willd.) Royle.	White Berry Bush		+		
<i>Homalanthus populneus</i> (Geiseler) Pax.*	Mouse Deer's Poplar	+	+	+	
<i>Jatropha integerrima</i> Jacq.	Spicy Jatropha	+		+	
<i>Macaranga rhizinoides</i> (Blume) Müll.Arg.	Mara Tapen	+	+		
<i>Macaranga tanarius</i> (L.) Müll.Arg.*	Mara	+	+		
<i>Manihot esculenta</i> Crantz	Cassava	+			
<i>Ricinus communis</i> L.	Castor Oil Bean	+	+	+	
Fabaceae					
<i>Acacia</i> sp.	Acacia		+	+	
<i>Aeschynomene americana</i> L.	American Joint Vetch	+			
<i>Arachis pintoii</i> Krap. & Greg	Yellow Peanut Plant			+	
<i>Bauhinia kockiana</i> Korth.	Kock's Bauhinia	+			
<i>Bauhinia purpurea</i> L.	Butterfly Tree	+			
<i>Caesalpinia sappan</i> L.	Sappanwood	+		+	

<i>Calliandra calothyrsus</i> Meisn.*	Red Calliandra	+	+	+	+	+	+	
<i>Cassia fistula</i> L.	Golden Shower Tree	+						
<i>Cassia siamea</i> Lamk.	Siamese Cassia		+					
<i>Centrosema pubescens</i> Benth.	Butterfly Pea	+		+				
<i>Delonix regia</i> (Boj. ex Hook.) Raf.	Flamboyant			+				
<i>Erythrina crista-galli</i> L.	Cockspur Coral Tree					+		
<i>Gliricidia sepium</i> (Jacq.) Walp.	Gliricidia					+		
<i>Indigofera tinctoria</i> L.	True Indigo	+						
<i>Lablab purpureus</i> (L.) Sweet	Hyacinth Bean	+						
<i>Leucaena leucocephala</i> (Lam.) de Wit.	White Popinac			+	+	+	+	
<i>Mimosa pigra</i> L.	Giant Sensitive Plant		+	+	+	+		
<i>Mimosa pudica</i> L.	Touch-Me-Not	+	+		+	+	+	
<i>Senna occidentalis</i> (L.) Link	Coffee Senna	+				+		
<i>Senna siamea</i> (Lam.) H.S. Irwin & Barneby	Siamese Cassia	+				+		
<i>Zapoteca portoricensis</i> (Jacq.) H.M.Hern.	White Stickpea	+		+		+		
Fagaceae								
<i>Castanopsis argentea</i> (Blume) A.DC.	Sweet Chestnut	+	+					
Gesneriaceae								
<i>Rhynchoglossum obliquum</i> Blume	Small-Flowered Tongue-Lip			+				
Gramineae								
<i>Trifolium repens</i> L.	Dutch Clover					+		
Haemodoraceae								
<i>Xipidium caeruleum</i> Aubl.	Walk Fast	+						
Heliconiaceae								
<i>Heliconia psittacorum</i> L.f.	Parrot Flower					+		
<i>Heliconia rostrata</i> Ruiz & Pav.	False Bird of Paradise	+		+		+		
Iridaceae								
<i>Gladiolus</i> sp.	Sword Lily			+				
<i>Neomarica longifolia</i> (Link & Otto) Sprague	Yellow Walking Iris	+		+		+		
Lamiaceae								
<i>Clerodendrum</i> × <i>speciosum</i> Dombrain	Java Glory Bean	+						
<i>Clerodendrum japonicum</i> (Thunb.) Sweet	Japanese Glorybower	+				+		
<i>Clinopodium gracile</i> (Benth.) Kuntze	Slender Wild Basil			+		+		
<i>Ocimum basilicum</i> L.	Sweet Basil	+						
<i>Phlomis</i> sp.	Jerusalem Sag			+	+			
<i>Plectranthus verticillatus</i> (L.f.) Druce	Swedish Ivy	+						
<i>Rothea serrata</i> (L.) Steane & Mabb.	Blue Fountain Bush	+		+				
<i>Salvia elegans</i> Vahl	Pineapple Sage	+						
<i>Salvia</i> sp.	Sage					+		
<i>Salvia splendens</i> Sellow ex Schult.	Scarlet Sage					+		
Lauraceae								
<i>Cinnamomum burmanni</i> (Nees & T.Nees) Blume.*	Cinnamon	+		+		+		
<i>Persea americana</i> Mill.	Avocado		+		+	+		
Liliaceae								
<i>Lilium formosanum</i> A.Wallace	Formosa Lily	+	+					

Lythraceae									
<i>Cuphea hyssopifolia</i> Kunth.	False Heather	+							
<i>Duabanga</i> sp.	-				+				
<i>Lagerstroemia speciosa</i> (L.) Pers.	Queen's Flower	+	+		+				
Magnoliaceae									
<i>Magnolia champaca</i> (L.) Baill. ex Pierre	Champak Tree	+	+						
<i>Michelia champaca</i> L.	Champaca		+			+			
Malvaceae									
<i>Abelmoschus manihot</i> (L.) Medik.	Sunset Hibiscus	+							
<i>Ceiba pentandra</i> (L.) Gaertn.*	White Silk Cotton Tree	+	+		+	+			
<i>Malvaviscus arboreus</i> Cav.	Wax Mallow	+		+					
<i>Sida hermaphrodita</i> (L.) Rusby	Virginia Fanpetals			+		+			
<i>Sida rhombifolia</i> L.	Arrowleaf Sida	+		+	+	+	+		
<i>Urena lobata</i> L.	Caesar Weed							+	
Melastomataceae									
<i>Clidemia hirta</i> (L.) D. Don	Hairy Clidemia	+		+		+			
<i>Melastoma malabathricum</i> L.	Asian Melastome	+		+		+			
<i>Tibouchina heteromalla</i> (D. Don.) Cogn.	Silverleafed Princess Flower							+	
<i>Tibouchina urvilleana</i> (DC.) Cogn.	Princess Flower			+		+			
Meliaceae									
<i>Khaya anthotheca</i> (Welw.) C.DC.*	East African Mahogany	+	+						
<i>Melia azedarach</i> L.	Persian Lilac							+	
<i>Toona sureni</i> (Blume) Merr.*	Suren Toon	+							
Menispermaceae									
<i>Arcangelisia flava</i> (L.) Merr.	Yellow Root	+							
Moraceae									
<i>Ficus hispida</i> L.f.*	Hairy Fig			+	+				
<i>Ficus padana</i> Burm. f.	White Hamerang	+							
Muntingiaceae									
<i>Muntingia calabura</i> L.	Jamaica Cherry		+	+					
Musaceae									
<i>Musa ornata</i> Roxb.	Flowering Banana	+							
<i>Musa x parasidica</i> L.	Banana	+		+					
Myrtaceae									
<i>Eucalyptus alba</i> Reinw	Timor White Gum	+	+						
<i>Eucalyptus deglupta</i> Blume	Rainbow Eucalyptus							+	
<i>Psidium guajava</i> L.	Guajava							+	
<i>Syzygium aqueum</i> (Burm.f.) Alston*	Water Apple	+	+			+	+		
<i>Syzygium aromaticum</i> (L.) Merr. & L.M.Perry.*	Clove			+					
<i>Syzygium cumini</i> (L.) Skeels.	Java Plum	+				+			
<i>Syzygium jambos</i> (L.) Alston	Rose Apple	+							
<i>Syzygium malaccense</i> (L.) Merr. & L.M.Perry.*	Malay Apple	+		+					
<i>Syzygium</i> sp.	-			+		+		+	

Pteridaceae*Pteridium* sp.

Bracken +

Rhamnaceae*Maesopsis eminii* Engl. *

Umbrella Tree + +

Rosaceae*Eriobotrya japonica* (Thunb.) Lindl.

Japanese Medlar +

Fragaria × *ananassa* (Weston) Duchesne

Strawberry +

Prunus sp.

Cherry + + +

Rosa sp.

Rose + +

Rubus rosifolius Sm.

Rose-Leaf Bramble + +

Sanguisorba minor Scop

Garden Burnet +

Rubiaceae*Gardenia jasminoides* J.Ellis

Kacapiring + + +

Haldina cordifolia Roxb.

Haldu + + +

Hamelia patens Jacq.

Fire Bush +

Ixora sp.

Red Ixora +

Mussaenda frondosa L.

Wild Mussaenda +

Richardia brasiliensis Gomes

Brazilian Calla-Lily + + + + +

Richardia scabra L.

Rough Mexican Clover + + + + + +

Rutaceae*Citrus sinensis* (L.) Osbeck

Orange + + + +

Salicaceae*Flacourtia rukam* Zoll. & Moritzi

Rukam + +

Sapotaceae*Palaquium obovatum* (Griff.) Engl.

White Gutta +

Solanaceae*Brugmansia arborea* (L) Sweet.

Angel's Trumpet (Yellow) + + +

Brugmansia candida Pers.

Angel's Trumpet (White) + + +

Brunfelsia uniflora (Pohl) D.Don

Manaca +

Capsicum annuum L.

Chili Pepper + + +

Capsicum frutescens L.

Chili Pepper + + +

Cestrum elegans (Brongn. ex Neumann) Schltld.

The Purple Cestrum + + + + +

Datura metel L.

Devil's Trumpet + + + + +

Physalis angulata L.

Angular Winter Cherry +

Solandra maxima (Moc. & Sessé ex Dunal)

Chalice Vine +

P.S.Green

Solanum americanum Mill.

American Black Nightshade +

Solanum diphyllum L.

Twin-leaf Nightshade + + +

Solanum erianthum D.Don

Potato Tree +

Solanum lycopersicum L.

Tomato + + + + +

Solanum macranthum Dunal

Giant Potato Tree + +

Solanum nigrum L.

Black Nightshade + + +

Solanum torvum Sw.

Turkey Berry + +

Solanum wrightii Benth.

Brazilian Potato Tree + +

Theaceae*Camellia sinensis* (L.) Kuntze

Tea Tree + +

In conclusion, *A. cerana* forages on a diverse array of plants in the Ir. H. Djuanda Forest Park, with trees and herbaceous plants being the primary sources of pollen. Among these, herbaceous flowering species were identified as the most promising food sources throughout the year. Notably, *T. diversifolia* and *C. calothyrsus* were dominant in all apiaries, flowered year-round, and produced pollen, marking them as key forage species. However, these species are invasive and should not be further promoted in enrichment strategies.

To ensure forage continuity, especially during the critical gap period from June to November, we recommend prioritizing the planting and conservation of non-invasive, year-round flowering species, such as *B. pilosa*, *D. celebica*, champaca (*Michelia champaca*), and *Z. mays*. These plants were observed to flower consistently and were also utilized by *A. cerana* for pollen collection. These plants should be considered for habitat enrichment in the Ir. H. Djuanda Forest Park. Improving floral diversity during the scarcity season is crucial not only for preventing colony absconding and improving honey yields, but also for enhancing the resilience of forest-pollinator interactions. A sustainable pollination service in tropical conservation forests depends on intentional forage provisioning and plant diversity management. Integrating targeted planting with ecological restoration efforts can contribute to both local beekeeping livelihoods and the health of forest ecosystems.

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