Diversity of Pollinator Insects in Anagro Garden, Bengkulu City, Indonesia

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Received: 13 August 2025, Revised: 25 August 2025, Available Online: 15 October 2025

Abstract *– Pollinator insects are considered beneficial organisms due to their essential role in plant pollination, supporting both ecological stability and agricultural productivity. However, land-use change and pesticide application may reduce pollinator diversity, making it necessary to identify existing species and assess their diversity as indicators of ecosystem health. This study aimed to identify the species and assess the diversity of pollinator insects in Anagro Garden, Bengkulu City. Field research was conducted from January to March 2025 using an exploratory survey method combined with direct observation. Sampling was carried out across multiple points within the garden. The results showed that pollinator insects observed in this area belonged to four insect orders. The calculated Shannon-Wiener Diversity Index (H') was 1.317, indicating a moderate level of species diversity. The Dominance Index (D) was 0.283, showing that no single order overwhelmingly dominated the assemblage. The Evenness Index (E) was 0.950, reflecting a high level of evenness and very uniform distribution of individuals among species. These findings suggest that although species abundances vary, the pollinator community remains balanced. The moderate diversity level indicates that the ecosystem quality in Anagro Garden is still fairly goodHowever, the study underscores the need for ongoing monitoring and habitat management to enhance pollinator diversity and maintain ecological resilience, particularly in semi-urban agroecosystems like those found in Bengkulu City.*

Keywords: *Anagro Garden, Bengkulu City, direct observation, pollinator insects, Shannon-Wiener Index*

INTRODUCTION

Indonesia is recognized as one of the world's megadiverse countries, exhibiting exceptional biodiversity that includes a remarkable array of insect species (Surin, 2020). Insects account for approximately 75% of all known animal species on Earth and display a wide range of body sizes, with lengths ranging from 0.25 mm to 330 mm and wingspans from 0.5 mm to 300 mm. These size variations are shaped by species-specific traits, environmental conditions, and biological functions (Stork *et al.*, 2021) This biodiversity is evident in both morphological features and ecological roles. For example, butterflies possess brightly colored, scaly wings; beetles are protected by hardened forewings (elytra); and flies have flexible, membranous wings (Choi & Jung, 2020).

Insects play pivotal roles in ecosystems as pollinators, decomposers, biological control agents, parasitoids, and bioindicators, with pollinator visitation rates directly linked to plant reproductive success (Majewska & Altizer, 2020). Pollinator insects are among the most important organisms in ecosystems, contributing approximately 35% to the global food supply (Febriyanti *et al.*, 2020). Their ecological services sustain agricultural productivity and enhance system resilience through natural pollination (Bartomeus *et al.*, 2021; Daniels *et al.*, 2020). This interaction increases both yield and quality of crops while benefiting farmer incomes (Singh, 2020).

However, intensive farming practices and widespread pesticide use have significantly reduced pollinator diversity and abundance (Widhiono *et al.*, 2022; Hall *et al.*, 2017; Tonietto *et al.*, 2020). Long-term observations have confirmed dramatic declines in bee and fly populations in areas of high agricultural intensification (Olsson *et al.*, 2025; Ecar *et al.*, 2018), negatively affecting entomogamy—the process of insect-mediated pollination (Saputri *et al.*, 2024). Key insect orders such as Lepidoptera, Hymenoptera, Diptera, and Coleoptera are essential for fruit and seed development and contribute to genetic variability (Dainese et al, 2019).

Pollinators are primarily attracted by plant shape, color, nectar, and pollen, while environmental factors like temperature, humidity, and wind modulate their activity (Li *et al.*, 2025). Interspecific competition for floral resources may also drive pollinators to shift habitats (Hansen *et al.*, 2020; Suhaila *et al.*, 2025). Threats such as land-use change, chemical input, and habitat fragmentation further endanger these vital insects. Reduced pollinator populations lead to diminished yields and ecological imbalance (Singh, 2020; Fortel *et al.*, 2020). Conversely, the decline in pollinator insect populations due to pesticide use, climate change, and habitat loss can disrupt natural pollination processes. More than 80% of pollination services are carried out by insects, particularly bees (Apoidea), butterflies (Lepidoptera), and beetles (Coleoptera). This condition leads to reduced crop yields and threatens ecosystem balance (Rhodes, 2018).

The Anagro Plantation, located in Betungan Village, Selebar District, Bengkulu City, is an agro-ecotourism area covering approximately 7 hectares and cultivated with various tropical fruit species such as date palm (*Phoenix dactylifera*), longan (*Dimocarpus longan*), water apple (*Syzygium aqueum*), crystal guava (*Psidium guajava* cv. Crystal), and sapodilla (*Manilkara zapota*). Its landscape forms a mosaic of crop blocks, newly planted areas, and open spaces designated for fruit-picking tourism and educational activities. Situated in a semi-urban area adjacent to main roads and toll access, the plantation lies on the boundary of an urban landscape. This condition may influence the availability of natural vegetation, habitats, and essential resources for sustaining pollinator populations. Therefore, addressing these challenges requires integrated efforts including habitat conservation, reduced reliance on synthetic pesticides, and enhanced farmer education (Kuriakose *et al.*, 2018).

In addition, while pollinator studies often emphasize species composition and diversity, environmental factors such as air temperature, humidity, and soil conditions play a crucial role in shaping pollinator activity and distribution. However, such abiotic influences have rarely been documented in semi-urban agro-ecotourism settings like Anagro Plantation. Therefore, integrating insect identification with microclimatic measurements is essential to provide a more comprehensive understanding of pollinator dynamics in this habitat.

Environmentally sustainable pest management approaches—such as botanical insecticides and biological control agents—are preferred due to their low toxicity and minimal environmental persistence (Eeraerts *et al.*, 2019). These interventions can strengthen pollinator resilience and support the maintenance of ecologically sound food production systems (Budianto & Sukendah, 2023). The implementation of such strategies is expected to safeguard and enhance pollinator abundance and diversity, thereby contributing to the sustainability and resilience of agroecosystems (Katumo et al., 2022).

MATERIALS AND METHODS

This study was conducted from January to March 2025 at the Anagro Garden in Bengkulu City Bengkulu Province, Indonesia. Observations and sample collections were carried out directly within the Anagro plantation. Materials used in this study included 50% alcohol, silica gel, camphor, and plant specimens from the Anagro Garden. Instruments included insect nets, forceps, gloves, envelopes or wax paper, a mobile phone camera, a stopwatch, a hand counter, worksheets, a field identification guidebook, writing tools, binoculars, a Four-in-One Environment Meter, and a thermo-hygrometer.

This research employed a quantitative descriptive design using an exploratory survey method. Insect sampling was conducted using the scan sampling technique, in which observers systematically scanned flowers within designated plots for a fixed period of five minutes every hour, twice daily (07:00–11:00 and 13:00–16:00). All insects visiting flowers during each scan were recorded and, when necessary, captured using insect nets or light traps for further identification. Apterygota insects, which are small wingless species with minimal metamorphosis and ventral abdominal appendages, were collected manually using forceps. The insect net was swept around cultivated plant canopies to trap insects, particularly those concealed within foliage.

Pollinator behavior was observed on selected three fruit species including longan (*Dimocarpus longan*), water apple (*Syzygium aqueum*), crystal guava (*Psidium guajava* cv. Crystal). These three fruit species were chosen because they represent the main commodities widely cultivated in Anagro Garden, their flowering period coincided with the study period, and they are known to rely primarily on insect pollination to achieve optimal fruit set. In addition, their flowers have distinct morphological characteristics that attract a diverse range of pollinating insects.

Ecological parameters were measured to complement insect diversity data and to understand the influence of environmental factors on pollinator activity. Soil temperature and humidity were recorded using a Four-in-One Environment Meter, while air temperature and relative humidity were measured with a thermo-hygrometer. Measurements were taken twice daily for five consecutive days (Karyati *et al.*, 2022). These abiotic data were collected to provide supporting information on the microclimatic conditions of the study site, which can affect the presence, behavior, and diversity of pollinator insects.

Pollinator diversity was assessed based on species richness and individual visitation frequencies, serving as indicators of ecosystem health (Eeraerts *et al.*, 2019). The *Shannon–Wiener* Diversity Index was calculated using:

$$H = -\sum pi \ln pi \text{ , where } pi = \frac{ni}{N}$$

The dominance index was calculated using Simpson's Dominance Index, with the formula:

$$C = \sum (ni/N)^2$$

The Scan Sampling data were analyzed quantitatively to determine the percentage of pollinator insect behavior in the Anagro Fruit Garden, based on the method by (Hermina & Huda, 2024), using the following formula:

$$\text{Insect behavior} = \frac{Activity\ Frequency}{Frequency\ of\ All\ Activities} x\ 100\%$$

RESULT AND DISCUSSION

A total of 41 individual pollinator insects representing 20 species across four major insect orders—*Hymenoptera*, *Lepidoptera*, *Odonata*, and *Coleoptera*—were identified in the Anagro Garden, Bengkulu City. These insects were observed visiting the flowers of three fruit plant species: Green Honey Apple (*Syzygium aqueum*), Guava (*Psidium guajava*), and Longan (*Dimocarpus longan*). The distribution of pollinator insects varied among plant species.

Hymenoptera was the most dominant order, present across all plant types, with representatives such as *Apis cerana*, *Xylocopa violacea*, *Ammophila sabulosa*, and *Vespa tropica*. Members of this group are widely recognized for their high pollination efficiency due to their morphological adaptations and floral constancy (Kline *et al.*, 2023). Recent studies by (Faraz *et al.*, 2023) further confirm that bees and their relatives are the dominant pollinators in both natural and agroecosystems due to their efficiency in exploiting floral resources.

Lepidoptera, comprising butterflies and moths, were mainly observed on *Syzygium aqueum* and *Psidium guajava*, reflecting their reliance on visual floral cues and nectar availability (Li *et al.*, 2025). *Odonata* were found perching and foraging among floral clusters and serve as useful bioindicators (Hansen *et al.*, 2020). *Coleoptera* were exclusively found on *Dimocarpus longan*, including beetle species such as *Cetonia aurata* and *Sitophilus granarius*, which have been shown to play an important role in mechanical pollination of densely clustered flowers (Budianto & Sukendah, 2023). The composition and abundance of pollinator insects per plant species are presented in Table 1.

Table 1. Composition of Pollinator Insects Observed on Fruit Plants in Anagro Garden

No	Plant Species	Order	Species	Number of Individuals
1	*Syzygium aqueum*	Lepidoptera	*Hypolimnas salmacis*	1
			Hipotion celerio	1
			Junonia orithya	2
			Neptis hylas	1
			Neptis sappho	1
		Hymenoptera	*Xylocopa violacea*	2
			Apis cerana	2
			Ammophila sabulosa	1
			Polyrhachis dives	2
2	*Psidium guajava*	Lepidoptera	*Appias lyncida*	1
			Leptophobia aripa	1
			Hypolimnas bolina	2
		Odonata	*Orthetrum sabina*	2
		Hymenoptera	*Apis cerana*	2
			Ammophila sabulosa	2
3	*Dimocarpus longan*	Odonata	*Orthetrum sabina*	3
		Hymenoptera	*Vespa tropica*	2
			Xylocopa violacea	2
		Coleoptera	*Tanymecus confuses*	2
			Sitophilus granaries	1
			Cetonia aurata	5
			Ixoria albonotata	2
		Lepidoptera	*Danaus chrysippus*	1
			Junonia hedonia	1
	Total			41

Among the three plant species, *Dimocarpus longan* supported the highest insect diversity, attracting all four observed orders. This richness may relate to the structural complexity and high floral output of longan inflorescences, which accommodate various insect foraging strategies. Diverse pollinator assemblages can synergistically enhance plant reproductive success, especially when multiple insect taxa are present (Claire, 2021).

Syzygium aqueum hosted 13 individual pollinators, including species from the orders Lepidoptera and Hymenoptera. Majewska and Altizer (2020) found that urban gardens with higher plant diversity and sunlight exposure significantly increased both pollinator abundance and species richness. The bright floral coloration and nectar availability of Green Honey Apple likely contribute to its attractiveness to bees and butterflies.

Psidium guajava recorded 10 individuals from the orders Lepidoptera, Hymenoptera, and Odonata. The presence of these diverse orders indicates a high ecological attractiveness, consistent with the findings of Daniels *et al.* (2020) that gardens with a variety of flowering plants are capable of attracting urban pollinators. This attractiveness is associated with the characteristics of guava flowers, which produce abundant nectar and pollen and have an open floral structure, making them easily accessible to a wide range of pollinating insects.

Floral traits and habitat characteristics play a central role in determining the attractiveness of plants to pollinator insects. The attraction of pollinators is influenced by multiple factors, including flower shape, color, and the number of available blossoms. An increase in nectar and pollen availability tends to draw more pollinators, thereby increasing visitation rates (Neumann *et al.*, 2024). Furthermore, vegetation diversity in the surrounding forest area offers essential microhabitats and supplementary floral resources, which serve as natural attractants for bees and other pollinating insects. Such biodiversity enhances both the abundance and species richness of pollinators within ecosystems (Ulyshen *et al.*, 2023). These findings reinforce the importance of diverse and resource-rich landscapes in supporting resilient pollinator communities.

Temporal Diversity of Pollinator Insects

Pollinator insect activity in the Anagro Garden exhibited notable temporal variation across observation periods. The majority of insect visits occurred between 07:00 and 08:00 WIB, coinciding with early morning conditions when air temperature averaged 26–27 °C and relative humidity ranged between 75–80%. These conditions are optimal for nectar secretion, as floral nectar production typically peaks under moderate temperatures and high humidity (Crall *et al.*, 2020). Such a pattern is consistent with the general behavior of diurnal pollinators, which prefer foraging under moderate sunlight and minimal heat stress (Li *et al.*, 2025). The integration of local abiotic data thus highlights how microclimatic conditions in the Anagro Garden directly influence pollinator foraging dynamics.

Figure 1 presents the number of pollinators recorded per plant species and insect order during daytime observation periods.

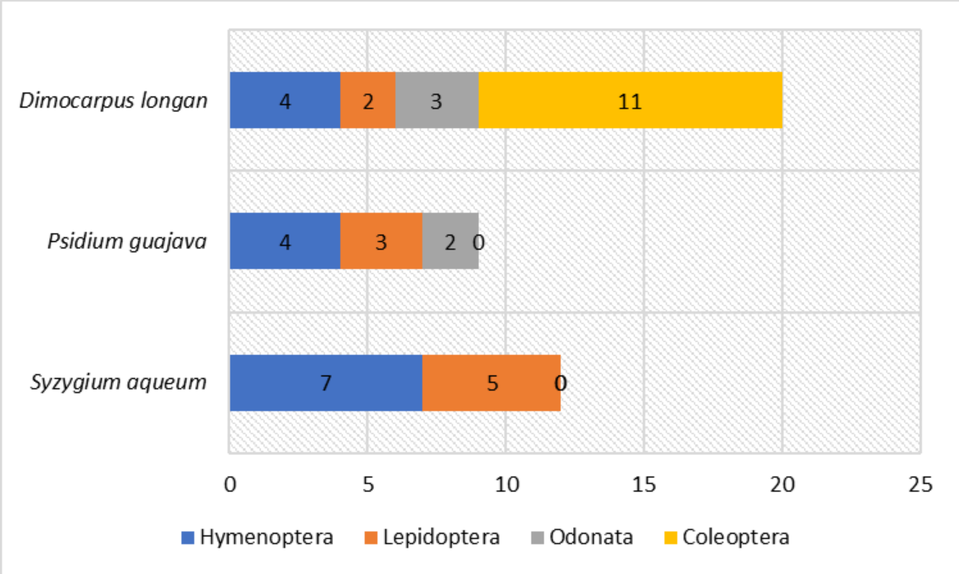

Figure 1. Diversity of Pollinator Insects Observed Between 07:00 - 15:00 WIB

Observations showed that most individuals were active between 07:00 and 11:00 WIB, especially among *Hymenoptera* and *Lepidoptera*. Activity decreased significantly after midday, likely due to rising temperatures and declining nectar availability. Pollinator richness and activity tend to concentrate in early daylight hours before thermal stress impacts flight behavior (Karyati et al., 2022)(Suhaila, 2025).

This result is in line with Singh (2020), who observed that *Apis cerana* showed peak foraging between 07:00–09:00 in tropical orchard systems. However, unlike conventional orchards that are often surrounded by extensive vegetation, the Anagro Garden is a semi-urban agro-ecotourism area with fragmented habitats and proximity to roads. Such landscape differences may influence the availability of floral resources and microclimatic stability, thereby shaping pollinator activity patterns. Similarly, Fortel (2020) demonstrated that urban pollinators adapt their activity based on sunlight and temperature dynamics, with wild bees tending to forage in the morning to avoid midday heat stress. In the context of Anagro Garden, this suggests that pollinator activity is not only temperature-dependent but also mediated by the unique interaction between urban edge effects and agricultural plantings, which distinguishes it from both rural orchards and fully urban gardens.

The temporal patterns observed here suggest that effective pollination occurs primarily in the early morning, making it essential to ensure floral availability and habitat conditions that support early-day foraging. According to Bartomeus (2021), pollination stability is enhanced when diurnal rhythms of insect activity are matched with peak flower receptivity—a crucial consideration for both conservation and agroecological planning.

Pollinator Diversity Index (Shannon-Wiener H′)

The pollinator insect diversity in Anagro Garden, Bengkulu City was analyzed using the Shannon-Wiener diversity index (H′). This index integrates both species richness (number of species) and species evenness (relative abundance), providing an overall picture of community diversity. The calculated Shannon-Wiener index value was H′ = 1.316, indicating a moderate level of species diversity. The results of the calculation are presented in Table 2.

Table 2. Pollinator Diversity Based on Shannon-Wiener Index

Insect Order	Total Individuals (n)	Proportion (pi)	Ln(pi)	–pi·Ln(pi)
Hymenoptera	15	0.36585	–1.005	0.3677
Lepidoptera	12	0.29268	–1.229	0.3596
Odonata	5	0.12195	–2.101	0.2563
Coleoptera	9	0.21951	–1.515	0.3325
Total				**1.316**

The Shannon-Wiener index (H') value of 1.316 indicates a moderate species diversity within the pollinator insect community, as it falls within the 1–3 range. This reflects the presence of several species with relatively balanced individual numbers, without dominance by any single species. Studies in (Khoirunnisa *et al.*, 2025) confirm that H' values between 1 and 3 represent communities where individuals are distributed fairly evenly among species. Therefore, an H' value of 1.316 suggests a pollinator community that is fairly diverse and relatively stable.

The findings support the notion that ecologically managed gardens can sustain both generalist and specialist pollinators (Daniels *et al.*, 2020). Although the current diversity is functional, it could be enhanced by increasing native floral resources, which would improve functional complementarity and pollination outcomes (Loy & Brosi, 2022). The presence of diverse and continuous floral resources ensures that different pollinator guilds can forage throughout the day and across seasons, thereby increasing the likelihood of effective pollen transfer. Furthermore, garden management practices that minimize pesticide use and maintain habitat heterogeneity provide safe foraging and nesting sites, which in turn enhance pollinator abundance and visitation rates. Such conditions directly support more consistent cross-pollination, higher fruit set, and improved crop productivity.

Pollinator Dominance Index (Simpson's C)

The dominance index of pollinator insect diversity in Anagro Garden, Bengkulu City, is C = 0.283, indicating a low level of dominance. This suggests that no single pollinator group overwhelmingly dominates the insect community. Instead, the distribution of individuals across the observed insect orders—Hymenoptera, Lepidoptera, Odonata, and Coleoptera—is relatively balanced, contributing to ecological stability and functional redundancy in pollination services.

The dominance index was calculated using Simpson's Index, which estimates the probability that two randomly selected individuals belong to the same species or group. Lower values indicate higher evenness and diversity. The results of the calculation are presented in Table 3.

Table 3. Pollinator Dominance Based on Simpson's Index

Insect Order	**Total Individuals (n)**	**Proportion (pi)**	**pi^2**
Hymenoptera	15	0.36585	0.1338
Lepidoptera	12	0.29268	0.0857
Odonata	5	0.12195	0.0149
Coleoptera	9	0.21951	0.0482
Total	**41**	—	**C = 0.2826**

This result indicates a low level of dominance and confirms that the pollinator community is not dominated by any single insect order. Instead, the distribution of individuals among Hymenoptera, Lepidoptera, Odonata, and Coleoptera is relatively balanced, contributing to ecological stability and functional redundancy in pollination services. This balanced distribution is likely influenced by the heterogeneous floral resources and microclimatic conditions in the Anagro Garden, which provide both nectar and pollen sources suitable for different pollinator guilds. The presence of diverse plant species with varying floral morphologies and blooming periods allows each order to exploit resources without strong interspecific competition, thereby maintaining ecological stability.

A low dominance index is considered a positive ecological indicator, as it reflects high community evenness and supports ecosystem resilience. Such conditions allow multiple insect taxa to play complementary roles in the pollination process, reducing the reliance on a single group and thereby minimizing the risk of pollination failure (Dainese *et al*, 2019).

In contrast, dominance often emerges in systems characterized by habitat simplification or intensive pesticide use, which tend to favor a few resilient taxa over others (Amorim, 2020). However, the current findings suggest that the Anagro Garden maintains a structurally diverse habitat that supports a wide variety of pollinator groups, limiting the overrepresentation of any particular order.

This observation is consistent with studies by Hall (2017), who emphasized that urban and semi-natural landscapes with heterogeneous habitats can sustain diverse insect pollinator communities. Similarly, Tonietto (2020) reported that pollinator assemblages in urban gardens tend to exhibit lower dominance and greater functional resilience, especially when native flowering plants are present.

Therefore, maintaining a low dominance index is essential for sustainable agroecosystems. It not only ensures a diverse and balanced pollinator community but also enhances crop productivity through more stable and efficient pollination services. This finding implies that management practices should prioritize maintaining plant diversity, reducing excessive pesticide use, and conserving natural habitats around farmland to prevent dominance by a single pollinator group. By implementing such strategies, farmers can promote long-term ecological resilience and secure consistent pollination services that directly support yield stability and food security.

Pollinator Evenness Index (E)

The Evenness Index (E) measures the uniformity of individual distribution among species or taxonomic groups within a community. An E value approaching 1 indicates a highly uniform distribution, where all groups have a relatively equal number of individuals. Conversely, values closer to 0 reflect uneven distributions, where one or a few groups dominate the community (Fadhilah *et al.*, 2022).

In this study, the calculated Evenness Index was E = 0.949, indicating a high level of evenness in the distribution of pollinator insects in Anagro Garden, Betungan, Bengkulu City. This suggests that the number of individuals across insect orders—Hymenoptera, Lepidoptera, Odonata, and Coleoptera—is relatively balanced, reinforcing ecological stability. The index was derived from a Shannon-Wiener diversity value of H′ = 1.316 and a total of S = 4 insect orders. Table 4 presents the data used in the calculation of the Evenness Index.

Table 4. Calculation of Pollinator Evenness Index (E)

Insect Order	Total Individuals (n)	Proportion (pi)	Ln(pi)	–pi·Ln(pi)
Hymenoptera	15	0.36585	–1.005	0.3677
Lepidoptera	12	0.29268	–1.229	0.3596
Odonata	5	0.12195	–2.101	0.2563
Coleoptera	9	0.21951	–1.515	0.3325
Total	**41**	—	—	**H′ = 1.316**
				E = **0.949**

Although the calculated Evenness Index reached E = 0.949, indicating a high level of uniformity in individual distribution across insect orders, field observations noted that Hymenoptera, particularly bees *(Apoidea),* were slightly more frequent observed due to their strong association with pollination activities. Their morphological traits, such as fine body hairs and specialized mouthparts, enhance their efficiency in collecting and transferring pollen. Many species also exhibit semi-social behavior that facilitates intensive and organized foraging. The availability of suitable flowering plants at the study site further contributed to their higher visitation frequency. Nevertheless, this variation was not substantial enough to disrupt overall community balance.

The high evenness value reflects an ecologically stable system, in which pollination services are likely to be resilient due to functional redundancy among insect taxa. The relatively balanced presence of Hymenoptera, Lepidoptera, Coleoptera, and Odonata ensures that various floral resources are utilized effectively through complementary foraging behaviors (Majewska & Altizer, 2020). This finding is consistent with Suhaila (2025), who reported that pollinator evenness in urban and semi-natural ecosystems enhances pollination efficiency by reducing interspecific competition and encouraging niche complementarity.

Maintaining or further enhancing pollinator evenness can be achieved through planting diverse nectar-producing flora, minimizing synthetic pesticide use, and conserving microhabitats that support varied insect foraging patterns (Amorim, 2020; Daniels *et al.*, 2020).

CONCLUSION

The study recorded 41 individual pollinator insects comprising 20 species across four orders—Hymenoptera, Lepidoptera, Odonata, and Coleoptera—in Anagro Garden, Bengkulu City. The composition and distribution of these pollinators suggest a moderately diverse and ecologically functional community. Temporal activity patterns showed that pollinator visits peaked in the morning, emphasizing the need to align conservation efforts with pollinator behavioral rhythms. The calculated Shannon-Wiener Diversity Index (H′ = 1.316), Dominance Index (D = 0.294), and Evenness Index (E = 0.949) further support the moderate diversity and balanced distribution among pollinator taxa.

These findings imply that urban green spaces, when managed ecologically, can sustain resilient pollinator communities. To improve pollinator diversity and stability, it is recommended that management policies prioritize the enrichment of native, year-round flowering plants and minimize pesticide use. Such interventions will not only enhance pollination services but also support urban biodiversity conservation efforts in the face of increasing anthropogenic pressures and climate variability.

ACKNOWLEDGEMENTS

The author expresses sincere gratitude to the management of Anagro Garden, Bengkulu City, for granting access and providing support during the research process. Appreciation is also extended to the local farmers and community members for their valuable insights and assistance in the field. Special thanks go to the academic advisor for their continuous guidance and constructive collaboration throughout the completion of this study. It is hoped that the findings presented herein will contribute meaningfully to pollinator insect conservation efforts and the advancement of sustainable agriculture practices in the Bengkulu region.

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