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Diversity of Insect Visitors to Oil Palm Flowers in Smallholder Plantations as a Potential Resource for Environment Based Learning in Education

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ABSTRACT

Purpose of the study: Insect visitors to oil palm flowers, an important component in the pollination process and ecosystem services, are evaluated for their diversity in this study. The research explores their potential as a resource for environment-based learning rooted in local contexts within smallholder plantations, aiming to raise awareness and support sustainable education practices in the community.

Methodology: Insects were collected using sweep nets, yellow pan traps, and direct observation. Identification was conducted using a Nikon SMZ445 stereo microscope and reference to entomological keys. Data analysis was carried out descriptively, focusing on species composition and abundance. An e-pocket book was developed as a learning resource.

Main Findings: The results showed a total of 50 morphospecies of insect visitors on both male and female oil palm flowers. The number of insect species visiting male flowers was higher, consisting of 38 morphospecies belonging to 21 families and 10 orders. The results of the study were developed into a local wisdom-based pocket book focused on the diversity of insect visitors to oil palm flowers in smallholder plantations. The learning resource was validated by content experts, design experts, media experts, and students, with an average score of 81.7%, indicating it is highly suitable for use in environment-based education.

Novelty/Originality of this study: This study highlights insect diversity in smallholder oil palm plantations, which is rarely documented. It also links ecological data with educational applications, providing a model for utilizing local biodiversity as a teaching resource in environmental and biology education.

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1. INTRODUCTION

Oil palm (*Elaeis guineensis*) is one of the most economically important crops in tropical regions, particularly in Indonesia, which is among the world's largest producers [1], [2]. While large-scale commercial plantations dominate the oil palm industry, a significant portion is managed by smallholder farmers. These smallholder plantations, typically characterized by more heterogeneous management and greater landscape diversity, provide unique ecological settings that support a range of flora and fauna [3]. Among the most ecologically important organisms associated with oil palm cultivation are insect flower visitors, many of which contribute to pollination, a vital ecosystem service for oil palm productivity [4]-[6].

Insects play a central role in pollination biology. For oil palm, although wind may contribute marginally, the primary agents of pollination are insects particularly species within the orders Coleoptera, Hymenoptera, and Diptera [7]. The presence and activity of these pollinators directly affect fruit set and yield. However, the diversity and abundance of these insect visitors can vary depending on plantation management, landscape structure, and floral resource availability [8], [9]. While numerous studies have focused on insect pollinators in large commercial plantations, relatively few have explored the composition and ecological roles of insect visitors in smallholder oil palm plantations, despite their growing prevalence in rural Indonesia [10]-[18]. Environment-based learning emphasizes the use of local natural resources and ecosystems as learning tools to build ecological literacy and critical thinking skills. It also promotes awareness of conservation and sustainable practices by engaging learners in direct observation, data collection, and analysis of natural phenomena [19]. The insect visitors of oil palm flowers represent a living, accessible biological resource that can be studied by students in both primary and secondary schools, particularly in rural and agricultural communities. Observing, identifying, and understanding these insects can cultivate students' appreciation of biodiversity, ecosystem services, and the importance of ecological balance in food production systems [20].

Furthermore, incorporating local ecological knowledge such as the behavior and identification of insects in oil palm plantations into learning materials supports the preservation of local wisdom while fostering community involvement in education [21], [22]. Educational media based on locally-sourced data, such as pocket books, modules, or field guides, have proven effective in increasing student engagement and comprehension. When students recognize that the organisms and ecosystems studied in class are part of their everyday environment, they are more likely to develop a lasting interest in science and environmental stewardship [23]. Despite its potential, the integration of agroecological knowledge, such as insect diversity, into formal education remains limited. Curriculum development in many regions still relies heavily on abstract and generalized content, often disconnected from students' local realities [24]. This disconnect poses a challenge for rural schools, where access to laboratory equipment and external resources may be limited, yet where rich biological diversity exists in the surrounding environment. Therefore, there is a need to explore innovative ways to utilize the local biodiversity found in smallholder agricultural systems as practical learning resources [25], [26].

This study was conducted to address these gaps by documenting the diversity of insect visitors to male and female oil palm flowers in smallholder plantations and analyzing their potential as a resource for environment-based learning. The research involved field identification of insect morphospecies, analysis of diversity patterns across oil palm habitat types, and development of an educational pocket book based on local wisdom. The results are expected to contribute not only to ecological knowledge and sustainable agriculture but also to the advancement of contextualized, environment-based education that empowers local communities.

2. RESEARCH METHOD

The research was conducted in smallholder oil palm plantations in Mamuju Regency, West Sulawesi Province. Insect specimen identification and data analysis were carried out at the Biology Laboratory, Faculty of Teacher Training and Education, Tadulako University, from February to April 2024. The study was conducted across three villages, each with four observation plots. In every plot, 15 oil palm trees were selected as male flower observation units, and 20 trees were selected for female flower observations. Each plot was named according to the oil palm species (S) and its surrounding habitat type: oil palm plantations (S), rubber plantations (K), human settlements (P), and secondary forests (H). The plots were numbered from 1 to 4. The habitat types included: oil palm plantations adjacent to rubber plantations (*Rubber plantation interaction*), oil palm plantations adjacent to other oil palm plantations (*Homogeneous interaction*), oil palm plantations adjacent to secondary forests (*Secondary forest interaction*), and oil palm plantations near human settlements (*Intensive human interaction*) (Figure 1). Each plot was replicated four times, resulting in 64 male flower observation units and 80 female flower observation units in total.

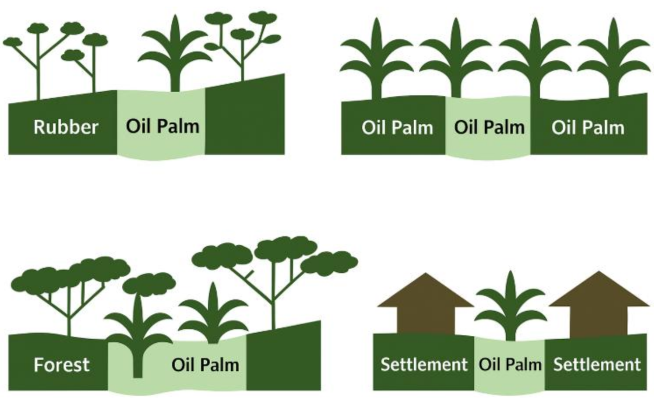

Figure 1. The habitat type scheme bordering oil palm plantations

The oil palm trees to be observed were selected by choosing 64 trees from four observation plots. All selected trees were of the same age, which was 4 years. Each plot consisted of 16 trees of uniform age. The observation focused on trees located along the observation line and not too far from the target habitat type (Figure 2). Observations were conducted by collecting male flowers from outside the core plots, ensuring that the flowers came from trees of the same age and were in the anthesis stage. Fresh fruit bunches (FFB) in anthesis were identified by the golden-yellow color of the flowers, the presence of pollen grains, and spikelets that had already opened. The male flowers were then cleaned using an aspirator and a brush to remove any insects that might still be present. After cleaning, the male flowers were placed within the observation plots. All flowers were placed at the same time and observed after 48 hours. Following the observation period, the flowers were collected and taken to the laboratory for insect collection. The insects found on the flowers were then identified up to the morphospecies level.

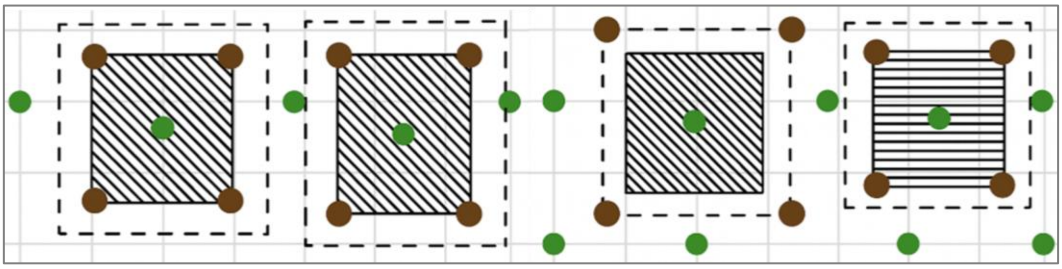

Figure 2. The oil palm tree used for male (brown) and female (green) flower observation

Observations on the frequency of insect visits were conducted on female oil palm flowers in anthesis within the observation plots (Figure 3). Female flowers in anthesis were characterized by a whitish-yellow color, a slightly mucilaginous texture, a stigma with three crescent-shaped, hairy lobes, and typically emitted a strong, fragrant aroma. Each observation lasted for 5 minutes and was repeated 20 times, resulting in a total observation time of 100 minutes. This method was a modification of the fixed sample method described by Dafni (1992). During the observation period, insects approaching the female oil palm flowers were recorded. Visiting insects were identified on the spot using an identification key from *An Introduction to the Study of Insects* (Borror et al., 1996), and the time of their visit to the female flowers was also noted.

The insect specimens collected from the field were subsequently identified using several entomological references. These included An Introduction to the Study of Insects, Manual of Nearctic Diptera, Identification Guide to the Ant Genera of the World, Identification Guide to the Ant Genera of Borneo, and Hymenoptera of the World: An Identification Guide to Families. These references provided the necessary morphological keys for classifying the insect visitors to the appropriate taxonomic levels.

Pollinator insect diversity was calculated using the Shannon-Wiener Diversity Index (H) (Magurran, 2004). Analysis of variance (ANOVA) was conducted to determine the relationship between pollinator insect diversity across different habitat types, using the software MINITAB® Release 16.12.0. To examine the dispersion patterns of insects within the four observed habitat types, dispersion and spatial distribution analyses. The relationship between distance differences among observation plots and variations in insect species composition was analyzed using the Mantel Test, performed with Microsoft Excel 2010.

Data analysis for assessment can be done using the following formula as in [27].

$$\text{Average} = \frac{\text{Total number of percentages}}{\text{Number of assessment aspect items}}$$

The average score obtained from the validation process is then interpreted based on eligibility criteria. These criteria classify the learning media into categories ranging from “Very unworthy” to “Very worthy” as shown in Table 1.

Table 1. Criteria for the eligibility of learning media

Score in percent (%)	Eligibility category
< 21	Very unworthy
21-40	Unworthy
41-60	Quite worthy
61-80	Worthy
81-100	Very worthy

3. RESULTS AND DISCUSSION

3.1. Abundance and Species Richness of Insect Visitors to Oil Palm Flowers

The insect visitors collected from male and female oil palm flowers consisted of 50 morphospecies (3,726 individuals) from 31 families and 12 orders. Insects visiting male flowers included 38 morphospecies (3,175 individuals) from 21 families and 10 orders. The most commonly found insects on male flowers were *E. kamerunicus* (Coleoptera: Curculionidae), *Forficula* sp. (Dermaptera: Forficulidae), *Diplatys* sp. (Dermaptera: Pygidicranidae), *Cardiocondyla sp.* (Hymenoptera: Formicidae), and Araneae (Arachnida) (Table 2). There were 20 morphospecies of insect visitors found on female flowers with an abundance of 418 individuals, belonging to 9 orders and 18 families (Figure 3). The insect visitors found on female flowers included *E. kamerunicus* (Coleoptera: Curculionidae) and *Megachilidae* (Hymenoptera: Megachilidae). Several families were found exclusively on female flowers, such as Apidae (Hymenoptera: Apidae), Chloropidae (Diptera: Chloropidae), Megachilidae (Hymenoptera: Megachilidae), Muscidae (Diptera: Muscidae), Syrphidae (Diptera: Syrphidae), and Tanaostigmatidae (Hymenoptera: Tanaostigmatidae).

The highest species richness on male flowers was found in oil palm plantations bordering forests, with 21 species. This is believed to be influenced by the natural ecosystem of the forest. Natural habitats (primary forests) tend to have higher insect species richness compared to intensive agricultural land, as natural ecosystems provide hosts and environmental conditions that play a significant role in the dominance of specific insect species [28]. Species found in all boundary types included *Araneae* (Arachnida), *Diplatys* sp. (Dermaptera: Pygidicranidae), *E. kamerunicus* (Coleoptera: Curculionidae), *Forficula* sp. (Dermaptera: Forficulidae), and *Cardiocondyla sp.* (Hymenoptera: Formicidae) (Figure 3). Each of these species plays different roles, such as predators (Araneae, *Cardiocondyla* sp., and *Diplatys* sp.) and pollinators (*E. kamerunicus*). The predator from the Pygidicranidae family, *Diplatys* sp., was found in large numbers in every plot. This insect was most commonly found in dry areas. According to [29], one habitat for Dermaptera members is within the crevices of dense oil palm fruit. Furthermore, these insects act as predators that prey on insect larvae (mostly from the orders Diptera and Coleoptera) and other small insects from the order Hemiptera. The highest number of individuals came from the Formicidae family in plots of oil palm bordering settlements, which is suspected to be due to the presence of other host plants planted by local residents and the influence of human activity. This is consistent with [30] statement that home gardens have higher invertebrate abundance, and also aligns with [31] findings that the high number of ant species in plantations shows that plantation development following deforestation increases species richness due to the presence of certain ant species associated with human activity.

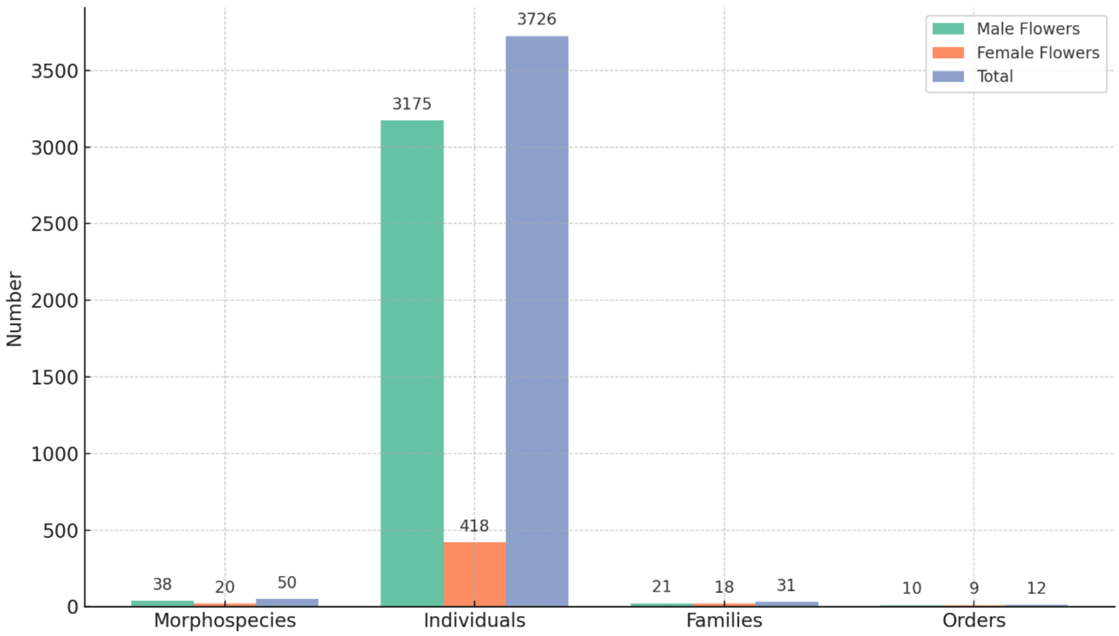

Figure 3. Comparison of insect visitors on male and female oil palm flowers

Most of the insect visitors on male flowers were predators, including members of the families Formicidae, Araneae, Reduviidae, Nabidae, Staphylinidae, Scorpiones, Dolichopodidae, and Stratiomyidae. According to [32], male flowers in anthesis emit a stronger scent than female flowers in anthesis because male flowers produce more volatile compounds. This is believed to be one of the factors attracting many predators to male flowers in search of nectar or food sources. These findings indicate that male oil palm flowers play an important role for predators by providing food sources and potentially supporting their survival. The implication of this finding is that oil palm plantations can serve as important "refugia" for predators. The presence of male flowers also serves as an attractant for pollinating insects in oil palm plantations, such as the weevil *E. kamerunicus* [33]. Figure 4 A shows the presence of various insect species in four observed habitat types (SK-SP-SS-SH). Overall, four insect species were found across all habitat types: *Cardiocondyla* sp., *Diplatys* sp., *E. kamerunicus*, and *Forficula* sp. Figure 4 B displays the occurrence of insect species across the same four habitat types. In total, only two insect species were found in all habitat types: *E. kamerunicus* and *Megachilidae*. The beetle *E. kamerunicus* is known to be an effective pollinator that aids in the formation of oil palm fruit bunches [34], while *Megachilidae* is a pollinating insect commonly found on wild plants [35].

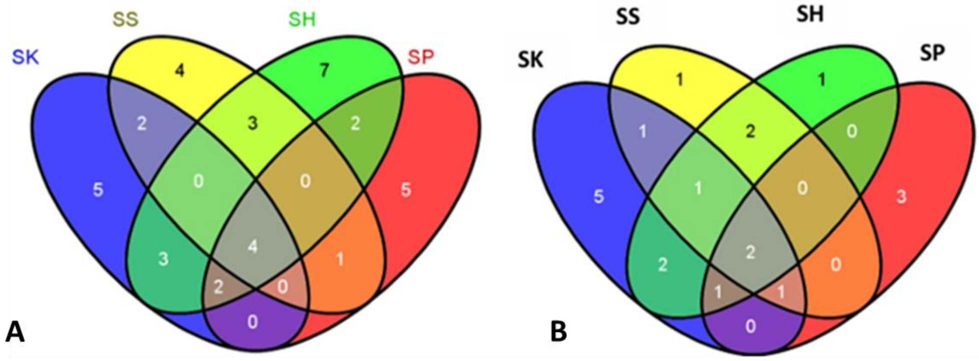

Figure 4. A. Venn diagram showing the number of insect species visiting male oil palm flowers in each observation plot (SK = Oil Palm–Rubber, SS = Oil Palm–Oil Palm, SH = Oil Palm–Forest, SP = Oil Palm–Settlement). B. Venn diagram showing the number of insect species visiting female oil palm flowers in each observation plot (SK = Oil Palm–Rubber, SS = Oil Palm–Oil Palm, SH = Oil Palm–Forest, SP = Oil Palm–Settlement).

High insect visitor diversity (H) was found on male flowers in three of the observed boundaries: oil palm bordering oil palm (H = 1.42), oil palm bordering forest (H = 1.45), and oil palm bordering settlements (H = 1.13) (Figure 5). The high diversity values were influenced by both the abundance of individuals and the number of species collected. For instance, in the oil palm–oil palm plot, a total of 280 individuals representing 14 species were collected, resulting in a high diversity value of 1.42. In contrast, although the oil palm–rubber plot had a higher abundance of individuals (1,422) and 16 species, the diversity index was low at 0.79. This was due to the low species composition diversity in that plot, indicating that a high number of individuals does not necessarily result in high species diversity. Meanwhile, the species composition in the oil palm–oil palm plot was more varied, which contributed to a higher diversity value despite the lower number of individuals. Based on Shannon-Wiener diversity criteria [36], the species diversity values for the three observed habitat types on male flowers can be considered high, as the H values deviate significantly from 0.

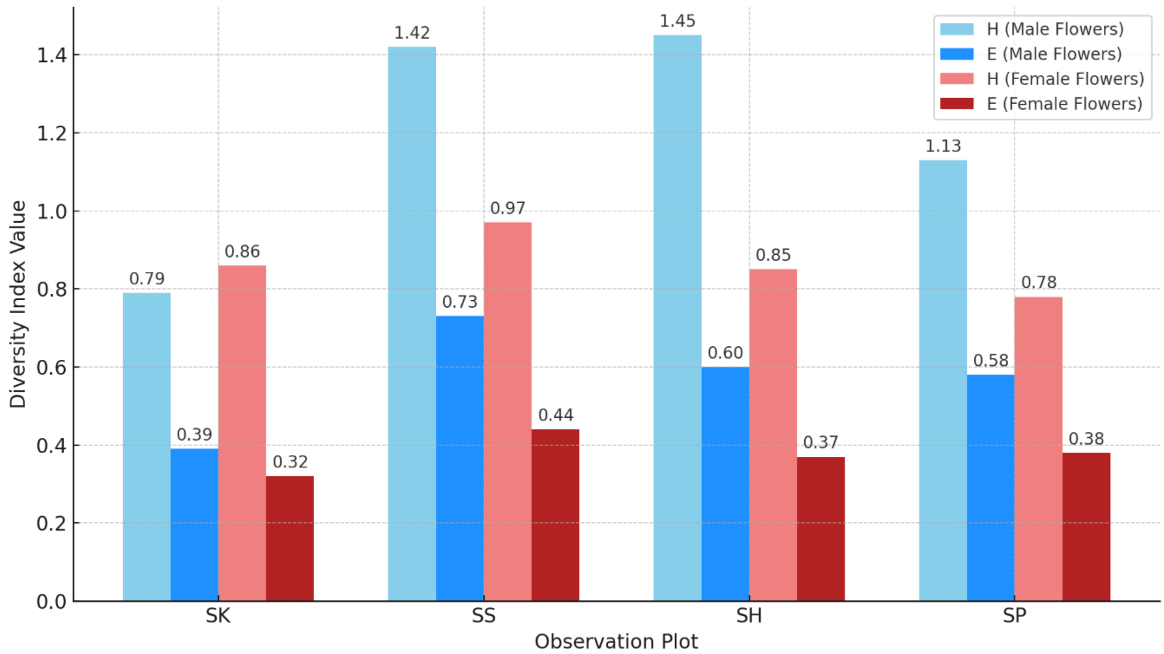

Figure 5. Diversity indices (H' and E) of insect visitors on oil palm flowers. SK = Oil Palm–Rubber, SS = Oil Palm–Oil Palm, SH = Oil Palm–Forest, SP = Oil Palm–Settlement.

Differences in diversity among the observed habitat types were influenced by several factors, including the landscape conditions of each habitat, the distance of the plots from natural forests, and the volatile compounds emitted by flowers during anthesis. Variations in landscape conditions are caused by the level of ecosystem diversity within each landscape. An increase in ecosystem diversity generally leads to greater insect diversity within that ecosystem [37]. The boundary types observed had relatively complex landscape conditions, allowing surrounding plants to serve as alternative hosts for visiting insects.

The content of volatile compounds released during flower anthesis is suspected to be one of the key factors influencing the level of insect visitor diversity and species composition. The flowering stage is a major factor determining the quality and quantity of volatiles produced by oil palm flowers. Palmitic acid, a volatile compound found in both male and female flowers, has been identified as playing an active role in attracting insects to visit the flowers [38]. Differences in the quantity of palmitic acid emitted by male and female flowers likely contribute to variations in the composition and diversity of insect visitors. According to [39], male oil palm flowers in anthesis produce a stronger aroma than female flowers due to the higher levels of volatile compounds they release. This may be one of the factors that attracts more insects to visit male oil palm flowers [40].

3.2. Dispersion Analysis of Dominant Insect Species Visiting Male Oil Palm Flowers

Dispersion analysis is used to observe the spatial distribution patterns of insects within an ecosystem. These distribution patterns reflect the interactions between insect behavior and environmental heterogeneity, particularly in relation to host plants that serve as sources of food and habitat [41], [42]. Foraging behavior, orientation, and host plant discovery are typically guided by plant-emitted volatile compounds associated with the search for nectar sources. The spatial distribution of visiting insects can influence diversity values, particularly alpha diversity, as it affects species structure and composition within a habitat. While the Shannon-Wiener diversity index [43] emphasizes species richness, understanding the distribution patterns becomes essential, as these patterns affect the types and numbers of insects that are either attracted to or avoid specific elements within their habitat.

Insect dispersion patterns can be categorized into three types: random, clumped, and uniform. In a random pattern, the presence of one individual is not influenced by the presence of others. Clumped dispersion occurs when individuals are attracted to specific parts of their environment, causing them to aggregate. In contrast, uniform dispersion is characterized by individuals avoiding one another [44]. In general, the dominant insect visitors to male oil palm flowers (Figure 6) include *Araneae*, *Cardiocondyla* sp., *Forficula* sp., and *Elaeidobius kamerunicus*. These dominant species serve different ecological roles: as predators, saprophages, and pollinators. Analysis of species proportion visiting male flowers showed that *Araneae 01* had the highest visitation rate in the oil palm oil palm border plot (SS), at 25%. The dispersion pattern of *Araneae 01* in this plot was uniform, indicated by a dispersion index (ID) of 0.80. As noted by [45], uniform dispersion suggests individuals tend to avoid one another.

In contrast, in the oil palm rubber border plot (SK), *Araneae 01* exhibited a clumped distribution pattern. This is likely due to the abundant availability of pollen and nectar in male oil palm flowers in that habitat, which attracted these spiders. Another dominant insect found was *Cardiocondyla* sp., a predatory ant. This species showed the highest presence in the oil palm forest border plot (SH), accounting for 37.5% of the total insect visitors. Dispersion analysis indicated that *Cardiocondyla* sp. consistently exhibited a clumped distribution pattern across all observed habitat types. The ants were observed visiting only a few flowers, resulting in individuals clustering on specific flowers. According to [46], clumped distribution occurs when individuals are drawn to certain environmental features, leading to aggregation. The presence of *Cardiocondyla* sp. suggests a strong attraction to male oil palm flowers, possibly influenced by the flower's blooming stage, which may affect the number of individuals visiting.

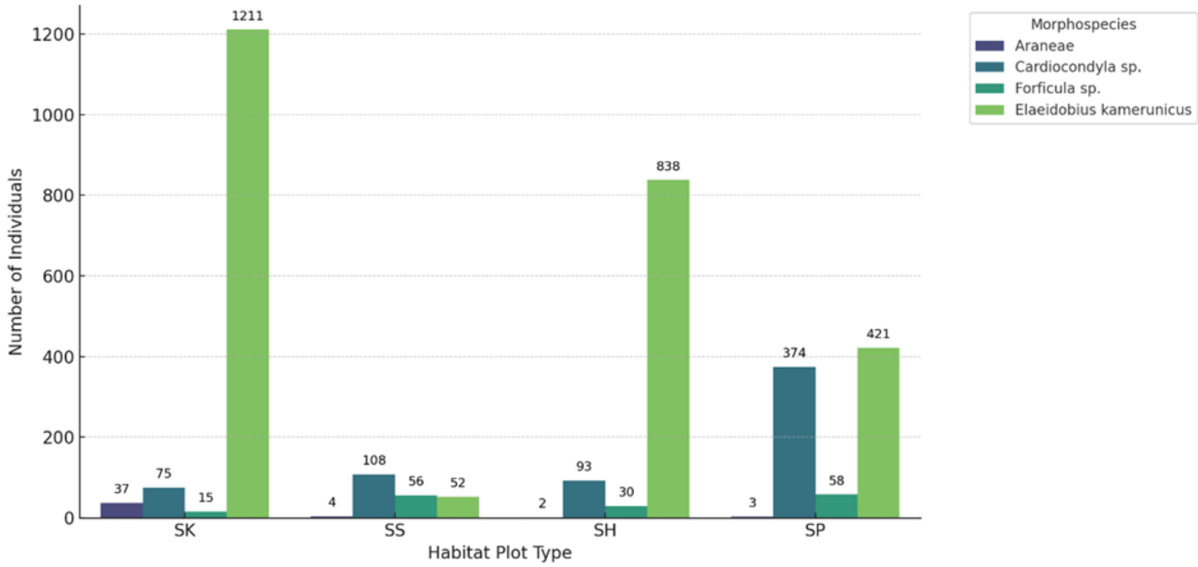

Figure 6. Dominant species dispersion by habitat type.

3.3. Percentage of Average Results of Pocket Book Feasibility Test

Based on the validation results conducted by the expert, the average score of the feasibility assessment for the learning resource in the form of an e-pocketbook indicates that it falls into the category of highly feasible for use in the learning process. With a feasibility percentage of 84.3%, this suggests that the e-pocketbook meets the essential criteria required to effectively support teaching and learning activities (Figure 6). The assessment covers several key aspects, including content accuracy, visual design, ease of use, and the relevance of the material to the learning objectives. Therefore, the e-pocketbook is considered a suitable and valuable educational tool that can enhance the overall quality of the learning experience and serve as an innovative and efficient alternative resource [24].

Learning resources encompass all elements that can assist students in acquiring knowledge and skills during the learning process. These resources may include individuals such as educators, instructional content such as textbooks or scientific data, learning environments, teaching methods, and media or tools that facilitate learning [25]. In the context of this study, learning resources were developed in the form of an e-pocket book, which was structured according to standard academic formatting. This format included a cover page, chapter titles, an introductory section, main content chapters, a conclusion, references, and appendices [24]. The development of the e-pocket book in this research was grounded in empirical data derived from the study of insect visitor diversity to oil palm flowers in smallholder plantations. These findings were then contextualized to serve as relevant and scientifically accurate learning materials that support the teaching of biology, particularly in the areas of ecology, entomology, and environmental science [26].

To ensure the quality and appropriateness of the e-pocket book as a learning resource, a thorough validation process was carried out involving three categories of experts: content experts, design experts, and media experts. The validation focused on identifying areas for improvement in terms of scientific content accuracy, visual design, user-friendliness, and overall educational value. The results of this expert validation showed that the e-pocket book received a score of 78.5% from content experts, 85.5% from design experts, and 76.5% from media experts. These scores reflect that the e-pocket book meets the required standards and is considered suitable for use as an educational medium.

In addition to expert validation, the e-pocket book was also tested with 30 students from the Biology Education Study Program. The students' responses yielded a very high average score of 96.6%, indicating that the material was not only scientifically appropriate but also engaging and easy to understand. When the results from both expert validation and student testing were averaged, the overall feasibility score of the e-pocket book was 84.3%, categorizing it as very feasible according to established standards, which state that a learning medium is considered "very feasible" when it achieves a score between 81% and 100%. The educational implications of this research are significant. First, the data on insect diversity visiting oil palm flowers provide authentic, field-based content that can enrich biology lessons, especially those dealing with pollination, biodiversity, and sustainable agriculture. Second, the successful development and validation of the e-pocket book demonstrate how local ecological studies can be translated into meaningful and engaging educational resources. This approach not only enhances student learning but also fosters environmental awareness and appreciation of local biodiversity. The use of region-specific examples also supports the integration of local knowledge into formal science education, creating more relevant and contextually grounded learning experiences, particularly for students in rural or agricultural communities.

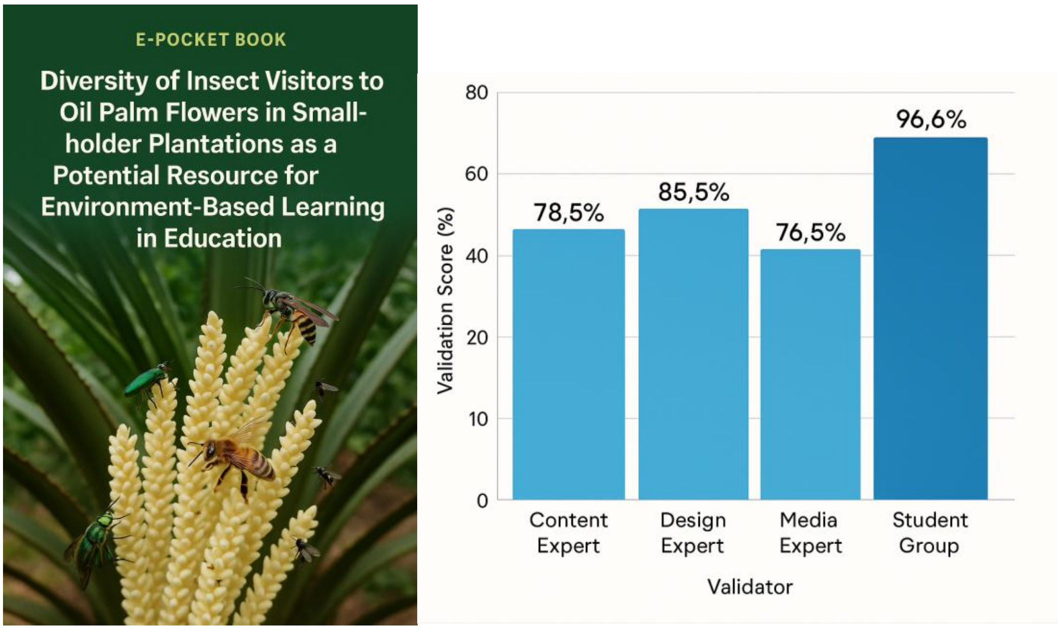

Figure 6. Cover and validation scores of e-pocket book feasibility test

4. CONCLUSION

This study found that *E. kamerunicus* dominated both male and female oil palm flowers, with *Forficula* sp., *Diplatys* sp., *Cardiocondyla* sp., and Araneae common on male flowers, and Megachilidae frequent on female flowers. Several insect families were exclusive to female flowers. The highest visitor diversity occurred near forest boundaries (H = 1.45), influenced by landscape conditions and floral volatiles. The findings are suitable for development into an 84.3%-feasible pocket book as a resource for environment-based learning in education.

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