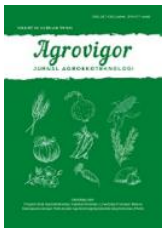
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Article

Insect Diversity on Sugar Palm (Arenga pinnata Merr.) and Their Correlation with Abiotic Factors in Lintau Buo Utara District, West Sumatra Province

Sandy Miranda Pranata[1], Zahlul Ikhsan[1*], Halimatus Syahdia Hasibuan[1]

[1]Department of Agroecotechnology, Faculty of Agriculture, Universitas Andalas, Padang, West Sumatra, Indonesia.

*Corresponding author: **Zahlul Ikhsan** (zahlulikhsan@agr.unand.ac.id)

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ABSTRACT

Sugar palm (*Arenga pinnata* Merr.) is a high-value commodity whose reproductive success depends heavily on insect-mediated pollination. However, empirical data regarding insect diversity and their activity patterns across different altitudinal gradients remain scarce. This study aimed to identify the diversity of pollinator and visitor insects and evaluate their correlation with abiotic factors across three altitude strata: 500–700 masl, 700–1000 masl, and >1000 masl in Lintau Buo Utara, West Sumatra. Using a survey method with purposive sampling, observations were conducted over four weeks utilizing malaise traps, yellow sticky traps, and visual counts. A total of 857 individuals were recorded, consisting of 712 pollinators (dominated by *Apis*, *Vespa*, *Episyrphus*, and *Polyrhachis*) and 145 visitors (including *Aphrophora*, *Macroglossum*, and *Spodoptera*). Ecological analysis revealed a moderate overall diversity index (H' = 2.04), with pollinators showing higher evenness (E = 0.92) compared to visitors (E = 0.89). The most optimal pollination activity was consistently observed at elevations of 700–1000 masl. Pearson correlation analysis demonstrated that rainfall and relative humidity were the primary environmental drivers, exhibiting significant and robust negative correlations with insect presence ($r = -0.94$, $p < 0.05$ for rainfall; $r = -0.64$, $p < 0.05$ for humidity), whereas air temperature showed a non-significant moderate influence ($p > 0.05$). Furthermore, a perfect positive correlation was found between pollinator and visitor patterns ($r = 1.00$, $p < 0.01$). These findings suggest that medium-altitude agroecosystems provide the most supportive microclimate for sugar palm pollinators, though high precipitation remains a critical limiting factor for their foraging efficiency.

INTRODUCTION

The Sugar palm (*Arenga pinnata* Merr.) is one of the palm species that has significant economic and ecological value in Indonesia. Sugar palm has various uses, ranging from food products, such as sap processed into palm sugar, to industrial raw materials, including gomuti fiber for the manufacture of various composite products (Ticoalu *et al*., 2012). All parts of this plant, from the roots to the leaves, can be utilized by local communities, making it a sustainable source of income for many.

The area of sugar palm plantation in West Sumatra is 1,409.19 Hectares, consisting of 1,043.09 hectares of productive plants and 312.70 hectares of non-productive plants, with a total production of 1,608.19 tons. The productivity figure is 1,541.75 kg/ha, and the area occupied by old or non-producing plants is 53.40 Ha. The area of sugar palm plantations in Tanah Datar Regency yields 385.00 ha of crops, while 7.00 ha of crops have not yielded (Badan Pusat Statistik, 2024). Two sub-districts have the largest harvest areas of sugar palm plantations, namely Sungayang District (299.40 ha) and Lintau Buo Utara District (100.00 ha). From the results of a survey in the field in Lintau Buo Utara District, sugar palms are most commonly found on the banks of rivers and in community gardens in Nagari Lubuk Jantan, as well as in Nagari Batu Bulek.

Although the potential of the Sugar palm is enormous, it still faces various challenges, including limited knowledge of proper management and cultivation. In addition, the environmental impacts of deforestation and land conversion to monoculture plantations, such as oil palm, also threaten the survival of these plants and the biodiversity around them (Khasanah *et al*., 2020). Therefore, research and development that focus on understanding palm trees and their role in the ecosystem are essential.

Several studies have identified and utilized specific aspects of the Sugar palm. Ticoalu et al. Ticoalu *et al*. (2012) highlighted the eye-catching properties of gomuti fiber in a composite context, while other research included the use of palm sap and food products (Withaningsih *et al.,* 2021). However, there are significant gaps in understanding the ecological role of these plants, particularly in the context of insect-pollinated crops, which are crucial for increased crop productivity. Many studies have not comprehensively linked the presence of Insect pollinators to the reproductive success of the Sugar palm, an important aspect of the cultivation and sustainability of this species.

Insect pollinators play a crucial role in maintaining the sustainability and productivity of the Sugar palm through pollination. The relationship between Insect pollinators and flowering plants is a form of mutualism, in which both organisms benefit from each other. Plants function as a source of feed in the form of nectar and pollen, as well as a shelter and breeding ground for insects. In contrast, insects assist plants in pollination by transferring pollen from the anther to the pistil, a crucial step in fruit and seed formation (Nepi, 2018; Heriza et al., 2025; Febriansyah et al., 2025). Thus, the presence of Insect pollinators not only contributes to the reproductive process of the sugar palm but also serves as an important indicator of the ecosystem's balance in the growing environment.

Research by Withaningsih *et al.* (2021) reported that insect pollinators of the order Hymenoptera, specifically the family Apidae, are predominantly found on Sugar palm compared to insects from other orders. The results of a study conducted by Saputra (2022) on Sugar palm in Nagari Lubuk Gadang Selatan, Sangir District, South Solok Regency, show that the Insect pollinators found belong to the genus Apis, while the Insect visitors found belong to the genus Forficula. A similar study by Novianto (2022) in Nagari Singkarak, X Koto Singkarak District, Solok Regency, also reported that Insect pollinators found on Sugar palm are bees of the genus Apis and Megachile. These Insect pollinators are more commonly found in the morning and evening periods. Meanwhile, the insect visitors observed across all three observation periods were ants of the genus *Polyrhachis.*

Several factors influence pollinator presence, including temperature. In highland areas, low temperatures can slow down the metabolism of insects so that the development of their life cycle becomes longer compared to insects in lowlands. High temperatures hinder pollinator insect foraging, while very low temperatures below 10°C can inhibit flight. High temperatures can also reduce the survival of Insect pollinators because they have limited tolerance to prolonged exposure to high temperatures, especially in the range of 35–45°C, which can cause physiological stress and decrease their activity and longevity (Abou-Shaara *et al*., 2012; Ikhsan, 2022). Syarkawi *et al.* (2015) noted that altitude affects environmental temperature,

and for ectothermic organisms such as insects, low temperatures can prolong development. Thus, the altitude of the place is closely related to air temperature, which plays an important role as a limiting factor in insect activity.

This research aims to answer several fundamental questions, namely: (1) How is the diversity of pollinators and Insect visitors found in Sugar palm in Lintau Buo Utara District, Tanah Datar Regency? (2) What is the relationship between the presence of Insect pollinators and environmental conditions at various heights of places found in the Sugar palm? To study the relationship between the presence of Insect pollinators and environmental factors such as temperature, humidity, and altitude, which can affect pollination activity and effectiveness.

The urgency of this research lies in ensuring the sustainability of Sugar palm production amid various environmental and social challenges. The novelty of this research lies in its integrative approach, which connects the understanding of Insect pollinators with the survival of the Sugar palm in the Lintau Buo Utara District. This research is expected to provide more comprehensive data on the pattern of insect visits with existing environmental conditions. In addition, by emphasizing the role of insects in pollination, it is hoped that there will be greater awareness of the need to protect various species of Insect pollinators that have not received much public attention so far.

MATERIALS AND METHODS

This research was conducted on community plantations in Lintau Buo Utara District, Tanah Datar Regency, West Sumatra Province, and insect identification was performed at the Biotechnology Laboratory of the Faculty of Animal Husbandry, Andalas University. The implementation time of this research is from April to September 2025. The ingredients used in this study are 70% alcohol, Sugar palm, and insects. The tools used in this study were swing nets, cameras, collection bottles, stereo microscopes, stationery, brushes, petri dishes, tweezers, plastic bottles, thermohygrometers, ladders, malaise traps, yellow sticky traps, label paper, millimeter paper, and counter timers.

Survey and Location

This study used a survey method with purposive sampling of locations based on three altitude strata: 500–700 masl, 700–1000 masl, and >1000 masl. Sampling amounted to 10% of the plant population. The criteria for selecting plants include palm trees with a productive age of more than 6 years that have simultaneously produced flowers, as well as healthy plants (free of severe diseases or pests). A coordinate point marks the location of the plant samples and serves as the research site.

Sampling and Observation of Frequency of Insect Visits

The design sampling combines passive traps (Malaise traps and yellow sticky traps) with active sampling (sweep nets and visual observation). Observations were conducted over four weeks, both in the morning and in the afternoon. A yellow sticky trap is a trap in the form of a yellow sheet that is coated with an adhesive to attract and ensnare insects, especially those that are attracted to the color yellow. This trap is widely used in insect ecology research and agricultural pest monitoring because it is highly effective in capturing small, flying insects. In this study, yellow sticky traps were installed by climbing a palm tree with a ladder, then placing a 20 × 25 cm trap secured to a plastic bottle. The trap was installed for 2 hours before observation on the palm flower cob, according to the sampling period.

Malaise traps are insect traps in the form of net tents that capitalize on the tendency of insects to fly towards light or upwards when they are obstructed. These traps are usually equipped with a container bottle filled with preservatives to collect insects passively over time. In this study, a malaise trap was installed around the Sugar palm that had previously been fitted with yellow sticky traps. The trap consists of a net with a span of 1.8 meters, supported by a pole or support tree, and a container bottle with a diameter of 10 cm and a height of 18 cm. After the traps are installed, direct observation of the Sugar palm is conducted by climbing the tree using a ladder for 30 minutes.

Then, the frequency of insect visits was observed using a visual control observational approach. This method is a modification of the method developed by Frei and Manhart (1992). This observation was made on the Sugar palm by climbing a tree using a ladder for 30 minutes. Observations were made at a distance of ±1 meter from the flower by directly observing the length of the visit and the number of insects that stopped by

receptive female flowers. Observation activities were conducted in two time periods: morning, from 07:00 to 09:00, and afternoon, from 15:00 to 17:00. Insects that visit flowers are observed to see whether or not pollen is attached to their bodies. If the insect does not carry pollen, it is categorized as an insect visitor. Observations were conducted four times at each research site, with a one-week time interval between observations. During observation, the frequency of insect visits was recorded using a counter timer, and insect activity on flowers was documented using a camera.

In addition to using observational methods, this study also uses passive traps and sweep nets to aid active insect sampling. A swing net is a circular, framed tool with a netting used to catch flying insects and those that land on plants. The insects caught with swing nets were placed in a collection bottle containing 70% alcohol and labeled as research samples.

Agroecosystem Observation

Agroecosystem observations are carried out through several steps, including documenting the conditions under which the observed palm grows, measuring humidity and temperature with a thermohygrometer, and recording rainfall with an ombrometer or rain gauge. Agroecosystem data are collected three times a week and then averaged.

Insect Identification

Identification of the insects collected at the observation site was carried out. The insects to be observed are taken from the collection bottle and cleaned with a brush. Then, they are placed in a petri dish using tweezers. It was then observed using a stereo microscope with a magnification adjusted for optimal viewing, and subsequently photographed with a Nikon SMZ1270 camera. This observation was conducted at the morphospecies level using the key books "Identification" (Borror *et al*., 2005), "Insect Pollinators" (Budi Purwantiningsih, 2014), and "Hymenoptera of the World: An Identification Guide to Families" (Henri Goulet and John T. Huber, 1993).

Data Analysis

The data obtained is then compiled, including the scientific name and morphological characteristics of each insect family. The data obtained were classified to the genus level. The data obtained is tabulated into tables and utilizes the data formula of the Shannon-Wiener Index (H`), the Species Richness Index, the Species Equality Index, the Dominance Index, the calculation of insect visit frequency, and the calculation of Pearson's Correlation.

To ensure the scientific validity of the observed relationships, the statistical analysis was expanded beyond basic correlation coefficients. Pearson correlation analysis was subjected to significance testing, with p-values calculated to determine if the relationships between insect activity and environmental variables were statistically significant at the $\alpha = 0.05$ level. Furthermore, data variance for insect visit frequency and duration was accounted for by reporting results as mean ± standard deviation (SD), providing a clearer measure of data dispersion over the four-week observation period.

RESULTS AND DISCUSSION

Environmental Conditions of the Research Location

At an altitude of 500–700 meters above sea level in the Lintau Buo Utara District, Tanah Datar Regency, the Sugar palm system is typically carried out through polyculture. The vegetation around the Sugar palm includes rice fields, cocoa, coconut, rubber, shrubs, and various other types of trees. The presence of such vegetation makes sugar palm management suboptimal, as the plants grow naturally among other plants without planned maintenance (Table 1).

At an altitude of 500-700 meters above sea level, rainfall yields an average of 13.75 mm, while air humidity yields an average of 61.50%, and temperature yields an average of 26.03 °C (Figure 1). Meanwhile, at an altitude of 700-1000 meters above sea level, the environmental conditions are not much different from those at an altitude of 500-700 meters above sea level, because it has a polyculture planting pattern where the vegetation around the growth of Sugar palm is in the area around rubber plantations, and also other tree areas. However, two locations with sugar palm plantations feature monoculture planting patterns, with palm trees planted exclusively (Table 1). Then, at an altitude of 700-1000 meters above sea level, rainfall yields an average of 15.75 mm, while air humidity yields an average of 62.25%, and temperature yields an average of 26.53 °C (Figure 1). Furthermore, at altitudes>1000 meters above sea level, the planting pattern is monoculture, with only sugar palm

plantations (Table 1). At this altitude, rainfall averages 13.25 mm, air humidity averages 61.75%, and the average temperature is 26.80 °C (Figure 1).

The Sugar palm at the research location is well-managed by the farmers. Still, for an altitude of 500 meters above sea level, the Sugar palm is not well managed by farmers, as they are more concerned with agricultural areas or other plantations. Still, for other heights, the Sugar palm is intensively cultivated; it is tapped, and the sap is collected to make palm sugar, which they sell to meet economic conditions. Regarding the information gathered from Sugar palm owners at the research site, Sugar palms are managed intensively, including sap harvesting, weed removal, frond cleaning, and fertilization once a year. The type of fertilizer used is NPK, with a dose of about 4-5 Kg/stem where the fertilizer is given 2 to 3 times a year, depending on the age of the plant and soil conditions, for the age of Sugar palm 1-3 years fertilizer is given 3 times a year at the beginning of the rainy season; mid-rainy season; and the end of the rainy season, while at the age of Sugar palm over 3 years it is enough to be given 3 times a year at the beginning and middle of the rainy season.

Air humidity is closely related to temperature and evapotranspiration. At higher altitudes, air humidity generally increases because lower temperatures reduce the rate of water evaporation. Sugar palm needs a humid environment, especially in the flowering and sap production phases. High humidity also creates microclimatic conditions that support the activity of soil microorganisms and the presence of Insect pollinators and other flower visitors (Somerville, 2000). Decreased air humidity caused by high temperatures in lowlands can disrupt water balance in plant tissues, leading to reduced productivity.

Table 1. Coordinate points, height of the place, and planting patterns

Num	Altitude (meters above sea level)	Coordinate Points	Planting Pattern
1	500-700 masl	0° 26' 33.479" S 100° 43' 52.879" E	Polyculture is used because rice fields are near the sugar palm plantations.
		0° 22' 56.269" S 100° 39' 33.666" E	Polyculture is used because cocoa plantations are adjacent to the sugar palm plantations.
		0° 24' 10.598" S 100° 43' 57.961" E	Polyculture is practiced because other plants, namely coconuts, are grown around the sugar palm.
		0° 23' 58.776" S 100° 43' 57.031" E	Polyculture is used because rubber plantations are adjacent to the sugar palm plantations.
		0° 24' 39.377" S 100° 44' 18.595" E	Polyculture is used because there are rubber plantations around the sugar palm
2	700-1000 masl	0° 22' 53.861" S 100° 40' 39.521" E	Polyculture is used because there are rubber plantations nearby.
		0° 23' 2.621" S 100° 41' 16.185" E	Monoculture
		0° 22' 53.965" S 100° 40' 39.513" E	Monoculture
3	>1000 masl	0° 22' 53.96" S 100° 40' 39.492" E	Monoculture
		0° 22' 54.142" LS 100° 40' 39.356" BT	Monoculture

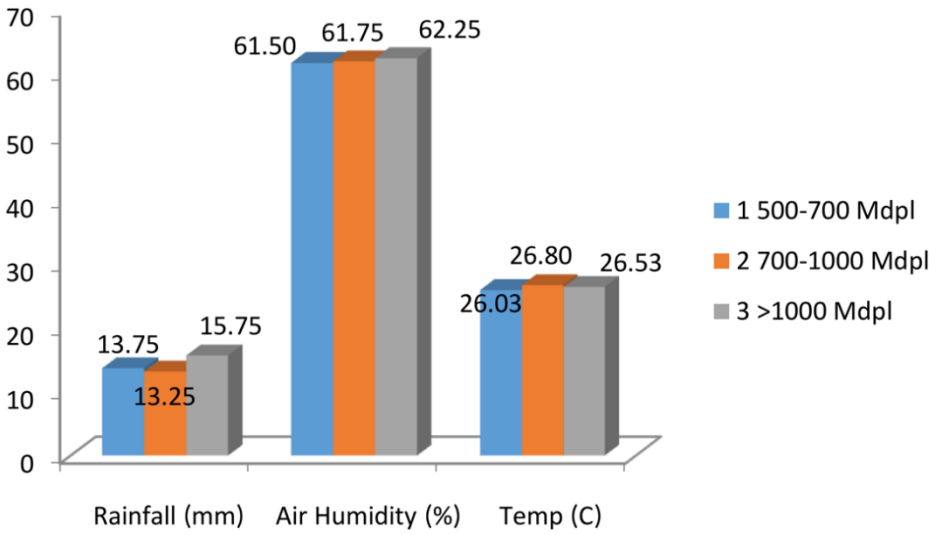


Figure 1. Average values of rainfall, humidity, and temperature on the sugar palm plantations

Rainfall is also strongly influenced by altitude through an orographic mechanism: wind-borne water vapor rises into the mountains and condenses. Therefore, areas at medium to high altitudes tend to receive higher, more evenly distributed rainfall than lowlands. Sugar palm requires rainfall between 1500 and 2500 mm per year to support the growth of roots, stems, and fronds, as well as maintain the availability of water for sap formation. Lack of rainfall can slow flowering and reduce sap quality, while excess water that is not drained properly can lead to root rot (Soemarwoto, 1985). The relationship between elevation and temperature, humidity, and rainfall suggests that environments with moderate elevation tend to provide the most optimal conditions for the cultivation and productivity of the Sugar palm. This altitude not only supports the vegetative and generative growth of plants but also creates a supportive habitat for Insect pollinators, such as bees, which play a crucial role in pollination. Therefore, in palm cultivation, selecting locations that account for local altitude and climate factors is a strategic step to increase yields and efficiency.

Palm Insects Pollinator

According to the research results, a total of 857 insect individuals were collected, comprising 712 Insect pollinators and 145 Insect visitors. The insect self-pollinating individuals were collected from various sources, including *Apis dorsata, Vespa tropica, Apis trigona, Episyrphus balteatus*, and *Polyrhachis sokolova*. As for insects, the individual visitors observed are *Aphrophoridae larvae, Macroglossum, Spodoptera, Anopheles, Tipuloidea, Anomala varicolor, Actia lamia, and Blaps mucronat*a. The results of the species diversity analysis showed that insect species diversity was 2.04, which was relatively low. The diversity of pollinating insect species was 1.42, a moderate value. In contrast, the diversity of insect visitor species was 0.62, also relatively low (Table 2).

The results of the species diversity analysis indicate sufficient species diversity and a distribution that is not too unequal among species. This indicates that the environment where the observation is conducted has sufficient ecological conditions to support the sustainability of various types of Insect pollinators. Conversely, if the value of H' is more than 3, then it reflects a very complex system with an even distribution of individuals between species. Meanwhile, an H' value of less than 1 indicates dominance by only one or two species and can indicate environmental conditions that do not support species diversity (Table 2).

Species richness is one of the important indicators that describes the number of different species found in a community or ecosystem. The greater the number of types found, the greater the type wealth. The results of the observations were obtained, with a type richness value of 0.592 for Insect pollinators, indicating that the observation location had low type diversity. In contrast, the species richness of visitors was 1.33, showing a relatively low type diversity.

Table 2. Diversity, richness, evenness, and dominance of insect species at the time of observation

Types of Insects	No	Genera	Sum	Diversity (H')		Species Richness (R)		Evenness (E)		Dominance (C)	
Insect pollinators	1	Apis	216	2,04	1,42	0,59		0,75	0,92	0,063	0,16
	2	Vespa	190	0,35				0,13		0,049	
	3	Trigona	64	0,68				0,25		0,006	
	4	Episyrphus	112	0,87				0,32		0,017	
	5	Polyrhachis	130	1,14				0,42		0,023	
Insect visitors	1	Aphrophora	1	1,42	0,62	6,76	1,33	0,53	0,89	0,000	0,007
	2	Macroglossm	16	1,43				0,53		0,000	
	3	Spodoptera	32	1,51				0,56		0,001	
	4	Anopheles	53	1,63				0,60		0,004	
	5	Tipula	25	1,80				0,66		0,001	
	6	Anomala	5	1,90				0,70		0,000	
	7	Actia	6	1,95				0,72		0,000	
	8	Blaps	7	1,99				0,73		0,000	
Total			857								

Given the relatively low wealth of these species, the types of insects they host are limited, putting them at risk of ecosystem imbalances. This can be related to the availability of feed sources, vegetation conditions, and environmental disturbances that are still relatively under control and uncontrolled. Species equality is an ecological parameter that measures the evenness of the distribution of individuals of each species within a community. This index indicates whether a community is dominated by a single or a few species, or whether the most prominent individuals are relatively evenly distributed across all species. Based on the observations, the equal distribution value for pollinating insect species was 0.92, indicating that the insect community at the observation location exhibited high evenness. In contrast, the Insect visitors had an evenness value of 0.89, indicating a high level of evenness in the insect community at the observation location. However, the level of evenness remained the same, but the most excellent equality value was observed among Insect pollinators, indicating that individual Insect pollinators dominate among the Insect visitors. Conditions like these suggest that species of these Insect pollinators can adapt and thrive. In contrast, other species may be subject to environmental pressures that limit their populations. Factors that affect evenness include resource availability, interpopulation interactions, and anthropogenic disturbances, such as pesticide use or habitat changes (Table 2).

The dominance index measures the degree of dominance of one or several species within a community. This index shows the proportion of dominant species in the overall population and is an important indicator of the ecosystem's balance. The greater the C index value, the greater the dominance of one or more types in the community. From the observations, the dominance value for Insect pollinators was 0.157, indicating that the observed pollinator insect community fell into the low dominance category. Similarly, the insect visitors' dominance value of 0.007 showed that the visiting insect community also fell into the low dominance category. This suggests that no single insect species dominates the community to a significant extent. In other words, individuals are distributed relatively evenly among several types of insects (Table 2).

Low dominance indicates that the insect community is in a balanced, ecologically healthy state, as the absence of a single dominant species allows interactions among species to run more harmoniously. Such balanced species diversity is crucial in supporting ecosystem processes, including pollination, as one of the primary ecological functions of these insects. In addition, the low value of the dominance index can be interpreted as relatively low environmental pressure on these communities, both from biotic (e.g., competition among species) and abiotic (e.g., habitat disturbance or pesticide use) factors. This allows different insect

species to coexist without one species dominating the others.

The Relationship Between Insects and the Environment in Palm Plants

In the observations that have been carried out, the number of insects found on Sugar palm in the morning period was recorded as many as 158 individuals at an altitude of 500–700 meters above sea level, 151 individuals at an altitude of 700–1000 meters above sea level, and 142 individuals at an altitude of 1000 meters above sea level. Meanwhile, during the afternoon, the number of observed insects was 134 at 500–700 meters above sea level, 146 at 700–1000 meters above sea level, and 126 at 1000 meters above sea level (Table 3).

In the morning observations, many insects were found on the Sugar palm. This is because insects are more active in the morning, visiting flowers, laying eggs, or foraging for food on the plant. In the first week of observation, the morning and evening periods were most common among the types of Insect pollinators at altitudes of 500-700 meters above sea level, while the most visited insects were also found at altitudes of 700-1000 meters above sea level.

In the second week of observation, the morning and evening periods yielded the most Insect pollinators at altitudes of 700-1000 meters above sea level. As with the type of visitor, insects were also most abundant at altitudes>1000 meters above sea level. This was because the second week of observation was rainy. Then, for observation in the third week, the morning and evening period, most types of Insect pollinators were found at an altitude of 700-1000 meters above sea level, and likewise, most types of visiting insects were found at an altitude of 500-700 meters above sea level, as well as in the second week, this can happen because the weather is rainy. Then for observation in the fourth week, the morning and evening periods were found the most Insect pollinators at an altitude of 700-1000 meters above sea level, while for the most insect visitors types found at an altitude of 500-700 meters above sea level, in the fourth week the weather was still rainy but not as heavy as in the third and second weeks (Table 3).

Pollination activity is highly dependent on the mobility and foraging behavior of insects that are highly sensitive to ambient temperature. In lowlands, high temperatures accelerate insect metabolism and shorten the time spent visiting flowers, but can increase the number of flowers visited (Fahem et al., 2004). Conversely, temperatures that are too low at high altitudes can reduce flight activity, thereby slowing down pollination rates.

Table 3. The types of insects obtained during the morning and evening observation period at the research site

No	Altitude (masl)	Types of Insects	Number of Insects in the Observation Period								Total
			Week								
			1		2		3		4		
			M	A	M	A	M	A	M	A	
1	500-700 masl	Insect pollinators	39	36	23	22	22	21	45	34	242
		Insect Visitors	9	6	7	5	6	5	7	5	50
2	700-1000 masl	Insect pollinators	33	35	27	25	23	24	43	39	249
		Insect Visitors	9	8	6	5	4	5	6	5	48
3	>1000 masl	Insect pollinators	36	34	22	20	20	19	37	33	221
		Insect Visitors	8	7	7	6	6	3	6	4	47
Total			134	126	92	83	81	77	144	120	857

Note: M= morning; A= Afternoon

Therefore, temperate altitudes are often the optimum zones because they provide moderate temperatures and high humidity, which support both plants and insects simultaneously (Rahbek, 1995). In addition to pollinators, many other insects that visit flowers, such as ants (*Polyrhachis*), flies, and mosquitoes (*Anopheles*), are also affected by changes in altitude. Some of these Insect visitors do not play a role in pollination but are present because of a source of food (nectar, plant fluids), shelter, or as part of the food chain. Insect visitor communities are generally more diverse in the lowlands, where temperature and humidity allow more species to breed and be active daily. However, at medium to high altitudes, although the number of species decreases, specialized species are often found that have adapted to extreme conditions (Körner, 2007).

The altitude of the location significantly influences the effectiveness of natural pollination, as it affects the number and type of Insect pollinators present (Hoiss et al., 2012). In lowlands, high diversity can increase the likelihood of cross-pollination, but the risk of competition and predation is also high (Bawa, 1990). At medium altitudes, the balance between microclimate, feed sources, and insect activity creates optimal conditions for sap productivity and fruit formation in the Sugar palm (Potts et al., 2003). Therefore, understanding the vertical distribution of Insect pollinators and flower visitors is crucial for biodiversity conservation and the ecological optimization of crop yields (Dafni, 1992).

Then, in the results of the frequency of pollinating insect visits at an altitude of 700-1000 meters above sea level, with the average number of each observation week, in the morning period, the results were 32.75 insect visits with a visit duration of 18.22 s, while in the afternoon period, the results were 30.75 insect visits with a visit duration of 18.04 s. Then, in the results of the frequency of pollinating insect visits, the average number of each observation week was >1000 meters above sea level with the average number of each observation week, in the morning period the results were 28.75 insect visits with a visit duration of 17.91 s, while in the afternoon period, the results were obtained namely 26.5 insect visits with a visit duration of 17.63 s (Table 4).

Table 4. Frequency and Duration of Pollinator Insect Visits (Mean ± SD)

No	Altitude (masl)	Time Period	Number of Visits (Mean ± SD)	Duration (sec) (Mean ± SD)
1	500–700	Morning (07.00–09.00)	31.00 ± 9.42	17.31 ± 0.44
		Afternoon (15.00–17.00)	28.25 ± 7.76	16.27 ± 0.80
2	700–1000	Morning (07.00–09.00)	32.75 ± 9.32	18.22 ± 0.62
		Afternoon (15.00–17.00)	30.75 ± 7.27	18.04 ± 0.64
3	>1000	Morning (07.00–09.00)	28.75 ± 8.88	17.91 ± 0.77
		Afternoon (15.00–17.00)	26.50 ± 8.02	17.63 ± 0.81

Furthermore, the analysis results showed that during the morning period (07:00–09:00), the Pearson correlation value of -0.134 indicated a very weak negative relationship between the number of visits and the duration of visits by Insect pollinators. This means that an increase in the number of insect visits tends to be followed by a decrease in visit duration; however, this relationship is very weak and almost statistically insignificant. Meanwhile, during the afternoon period (15:00–17:00), the correlation value of -0.040 also indicates a very weak negative relationship between the two variables. This indicates that in the afternoon, the number of insect visits does not show a meaningful linear relationship with visit duration (Table 5).

Regarding the temporal patterns of pollination, the relationships between the number of visits and their duration were negligible. During the morning period (07:00–09:00), the Pearson correlation was very weak and negative (r = -0.134), while the afternoon period (15:00–17:00) showed an even lower correlation (r = -0.040). These values fall within the range of almost no correlation, indicating that an increase in visit frequency does not predictably lead to shorter visit durations in this habitat. This lack of a linear relationship suggests that insect behavior on *Arenga pinnata* is likely governed by complex interactions of nectar availability and microclimatic shifts rather than a simple trade-off between frequency and time.

Pearson's correlation coefficients across both observation periods showed no strong relationship between the number of pollinator insect visits and the duration of visits. This can be caused by a variety of external factors that affect insect behavior, such as microclimatic conditions (temperature, humidity, precipitation), nectar availability, and insect activity itself, which may not be directly correlated with the quantity of visits. According to Sugiyono (2017), the correlation value falls within the range of -0.20 to 0.20 and is categorized as a very low correlation or almost no correlation. Thus, despite differences in the number of visits and the duration of each visit, the two do not show a statistically significant relationship.

Table 5. Pearson's correlation value between the number of visits and the duration of pollinator insect visits

Observation Period	Number of Visits	Duration
07.00-09.00	1	-0,134
15.00-17.00	1	-0,040

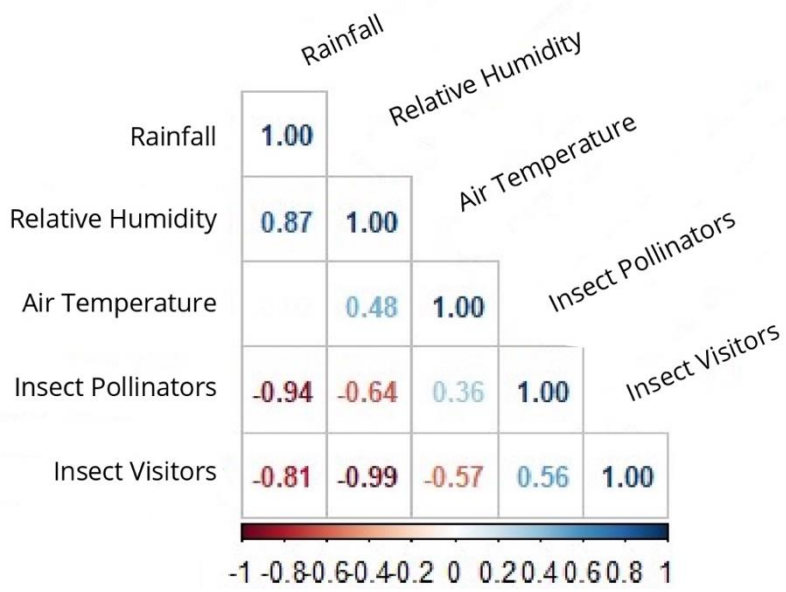


Figure 2. Pearson's correlation of the relationship between insects and agroecosystems

Research by Dafni (1992) suggests that pollination effectiveness is significantly influenced by the duration of insect visits to flowers: the longer the interaction time between insects and flower organs, the greater the likelihood of successful pollination. This is also reinforced by Heinrich (1979), who showed that bees and other Insect pollinators regulate the duration of visits according to the quality and quantity of nectar available. At the time of observation, the relationship between agroecosystem characteristics (such as humidity, air temperature, and rainfall) and the presence, abundance, and diversity of Insect pollinators and Insect visitors was also examined.

The results of the analysis of the relationship between rainfall characteristics and Insect pollinators and visitors showed that rainfall had a robust negative correlation with the number of Insect pollinators (r = -0.94) and visiting insects (r = -0.81). This indicates that the higher the rainfall, the more the existence and activity of the two insect groups tend to decrease. Wet conditions resulting from excessive rainfall can hinder insect foraging and pollination.

The analysis of agroecosystem characteristics identifies rainfall and relative humidity as the primary abiotic drivers influencing insect presence (Figure 2). Rainfall exhibited a robust negative correlation with the number of insect pollinators (r = -0.94) and visiting insects (r = -0.81), indicating that precipitation significantly hinders foraging and flight activity. Relative humidity followed a similar trend, showing an almost perfect negative correlation with visiting insects (r = -0.99) and a strong negative correlation with

pollinators (r = -0.64). In contrast, air temperature presented a moderate to weak negative correlation (r = -0.36 for pollinators; r = -0.57 for visitors), suggesting it is a secondary factor compared to moisture-related variables at this specific study site.

Furthermore, the analysis of the relationship between relative humidity characteristics and Insect pollinators revealed a robust negative correlation with Insect pollinators (r = -0.64) and an almost perfect correlation with visiting insects (r = -0.99). This correlation suggests that high humidity may reduce insect activity. Insects tend to be more active in moderate humidity conditions, as extreme humidity can interfere with their metabolism. Meanwhile, the analysis of the relationship between air temperature characteristics and Insect pollinators and visitors revealed a moderate to weak negative correlation with Insect pollinators (r = -0.36) and visiting insects (r = -0.57). This suggests that temperature is not a dominant factor influencing insect presence at the study site, although extreme temperatures can still affect their activity. Then, the analysis of the relationship between insects showed a perfect positive correlation (r = 1.00) between Insect pollinators and visiting insects. This suggests that the two are present in the same pattern, possibly because they respond to similar agroecosystem conditions or because of overlap in ecological functions and resources utilized. The results of this Pearson correlation indicate that rainfall and relative humidity are the two primary factors in the agroecosystem that most significantly impact the presence of Insect pollinators and visitors.

CONCLUSION

The study revealed that the principal insect pollinators associated with sugar palm (Arenga pinnata Merr.) belonged to the genus Apis, while other pollinators included Vespa, Episyrphus, and Polyrhachis. Insect visitors were represented by several genera, including Aphrophora, Macroglossum, Spodoptera, Anopheles, Tipula, Anomala, Actia, and Blaps. Elevation significantly influenced insect distribution and activity, with areas at 700–1,000 m above sea level providing the most favorable conditions for pollinator activity due to moderate temperature and relative humidity. Furthermore, rainfall and relative humidity had a greater influence on the abundance and activity of insect pollinators and visitors than air temperature, exhibiting a strong negative correlation with insect abundance. Correlation analysis also indicated a very strong positive relationship between the abundance of insect pollinators and insect visitors, suggesting that both groups exhibited similar occurrence patterns within the sugar palm ecosystem.

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