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Exploring vegetation's role in enhancing ant-based coffee berry borer control in an agroforestry system

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Abstract. *Haryadi NT, Kurnianto AS, Dewi N, Sukma GAK, Devarigata ES, Suyitno YMR, Magvira NL, Firdaus AS. 2024. Exploring vegetation's role in enhancing ant-based coffee berry borer control in an agroforestry system. Biodiversitas 25: 491-501.* The coffee industry faces a serious threat from coffee berry borer pests, causing significant economic losses. This research aims to explore the potential of using ants as a biological control method in coffee plantations, as well as the influence of shade on ant communities. The research was conducted in the Sumberjambe and Silo Sub-districts using purposive sampling methods to collect ant specimens with the beating sheet method. Specimens were identified in the laboratory, and data were analyzed using the Shannon-Wiener diversity index, the Evenness index, and the Margalef species richness index. The results showed 17 ant genera in Sumberjambe and 13 in Silo, with 7 of them acting as predators. The analysis indicated low diversity (H'=0.88-1.56) with the dominance of the Dolichoderus and Lasius genera at both locations. A high evenness index in Sumberjambe (E=0.75) indicated a uniform distribution, whereas a moderate value in Silo indicated a less uniform ant distribution (E=0.45). Species richness at both locations was considered low (Dmg=0.66-0.91). Comparative tests between the two locations did not show a significant difference in the diversity of ants that could potentially act as predators. This study also includes an analysis of tree species vegetation at the agroforestry sites, with *Albizia chinensis* trees showing the highest importance value in Silo (INP=209.37). This indicates the significant role of this plant in the ant agroforestry community. The Tapinoma genus (Pearson corr.=0.996, p-value=0.0467) and Solenopsis genus (Pearson corr.=0.993, p-value=0.0432) showed a very strong positive correlation with *Albizia* plants. However, some other combinations showed weaker correlations or approached zero, indicating that the number of vegetation species did not greatly influence their presence or abundance. This research provides insight into the diversity of ants, their potential role as predators of the coffee berry borer, and the relationship between ants and vegetation on two coffee-based agroforestry fields in Jember District, Indonesia.

Keywords: Agroforestry system, ant diversity, biological control, species richness, vegetation influence

INTRODUCTION

Coffee cultivation in Indonesia holds a paramount position in the nation's agricultural economy, being one of the leading sources of foreign exchange earnings (Byrareddy et al. 2019). As of 2022, Indonesia became the third-largest coffee producer worldwide, trailing behind Brazil and Vietnam; the yearly production statistics marked an increase to 794.8 tons, approximately 1.1% higher than the previous year's yield (Panggabean et al. 2021). This increment underscores the strategic significance of coffee in Indonesia's agricultural sector, necessitating advanced and sustainable cultivation techniques to sustain and enhance productivity. The challenge of maintaining high productivity in coffee cultivation is largely impacted by pest infestations, specifically by the coffee berry borer (*Hypothenemus hampei* Ferrari, 1867). This pest poses a significant threat to coffee crops, with research by (Morris and Perfecto 2016) highlighting its detrimental impact. The infestations by *H. hampei* can cause extensive damage, accounting for a 60% yield reduction in Mexico and 50-90% in Colombia (Sanabria et al. 2014; Vega et al. 2015). The severity of these infestations is quantified by yield reduction and the degradation of coffee quality. The borer's activity, characterized by boring holes into coffee berries and laying eggs, detrimentally affects the beans, leading to a noticeable decline in taste and overall quality. The economic repercussions of these pest attacks are significant, with annual losses estimated at 500 million dollars in Ethiopia, 215-358 million dollars in Brazil, and approximately 625 billion Rupiah (equivalent to around 6.7 million US dollars in Indonesia (Oliveira et al. 2013).

Conventional insecticide pest control methods have proven relatively ineffective against the coffee berry borer. The ineffectiveness is primarily due to the reproductive behavior of the female borers, who lay eggs inside the coffee berries, thereby shielding the larvae from external insecticidal applications (Morris et al. 2015). Moreover, the lifecycle of the female coffee berry borer, which is significantly longer than that of the male, and spent entirely within the coffee fruit, further complicating control measures (Infante 2018). Given these challenges, exploring natural predators like ants has gained attention as an alternative pest control strategy. Ants (Formicidae: Hymenoptera) dominate many ecosystems and their role as natural predators is particularly effective in agroecosystems (Beilhe et al. 2020). Studies by

Armbrecht and Gallego (2007) have demonstrated the efficacy of ants in controlling coffee pests, including the coffee berry borer. Ants' biological and ecological traits, such as predatory behavior and adaptability, make them suitable candidates for biocontrol in coffee plantations. Research on ant species capable of preying on coffee berry borers has been conducted across different coffee-producing countries. In Mexico, species such as *Wasmannia auropunctata* (Roger, 1863) and *Solenopsis picea* (Emery, 1896) have been identified (Morris and Perfecto 2016). *Odontomachus* sp. and *Linepithema neotropicum* (Wild, 2007) are recorded in Costa Rica, while in Martinique, *Azteca instabilis* (Smith, 1862) have a significant role (Trible and Carroll 2014; Offenberg 2015). Colombian coffee plantations have seen a reduction in borer attacks through the introduction of *Crematogaster* sp. and *Pheidole* sp., with reductions in borer attacks by up to 7% (Sanabria et al. 2014).

In Indonesia, extensive research has been conducted on the role of ants as natural enemies, particularly in cocoa plantations (Thurman et al. 2019; Saleh et al. 2020). However, research on the diversity and potential of ants as predators of coffee berry borers on coffee plants remains limited. Understanding this diversity and the population dynamics of predatory ants in coffee agroforestry systems is crucial. The ongoing research focuses on identifying and quantifying the various ant species in coffee-based agroforestry systems, particularly in the Jember District, and assessing their effectiveness as natural predators against the coffee berry borer (*H. hampei*). This research aims to explore the potential of using ants as a biological control method in coffee plantations, as well as the influence of shade on ant communities. This study also offers a sustainable and environmentally friendly alternative to chemical pest controls by determining the diversity and effectiveness of ants as natural predators of *H. hampei*, which is crucial for the long-term health and productivity of coffee plantations in Indonesia.

MATERIALS AND METHODS

Research procedure

The research was conducted in July 2023 in the Sumberjambe and Silo Sub-districts, Jember District, East Java, Indonesia (Figure 1). Sampling points were determined using the purposive sampling method. Several criteria established for purposive sampling include; (i) Having the same variety of coffee in each management type (Robusta *Coffea canephora*), (ii) The coffee plants being in the fruiting stage, and (iii) Having ant colonies on the coffee trees. The number of coffee plants used as samples was 10% of the total area of coffee land.

Ant sampling was conducted using the Beating sheet method. A white cloth measuring 90 cm x 90 cm was spread under qualifying coffee plants, and then the leaves were beaten 5 times using a 50 cm long wooden beater. Ants that fell onto the white cloth were collected using a wet brush and transferred into jam jars containing 70% alcohol. There were 24 sampling trees at each research location.

Ant identification was done using a microscope (Nikon Stereo Microscope SMZ 745). There were 2 books used as key identification sources for ants, 'Identification Guide to the Ant Genera of the World' (Bolton 1994), 'The Formicidae (Hymenoptera) of Fennoscandia and Denmark' (Collingwood 1979). Identification was carried out up to the genus level. The results were tabulated into a database using Ms. Excel. Analysis of shade plant vegetation for coffee was carried out at two research locations using plots measuring 20 m x 20 m (quadrant method); shade plants overshadow coffee plants or are taller than coffee plants. The parameters required for data collection included species, number of individuals per species, and Diameter at Breast Height (DBH) on albizia, mahagoni and pinus (Hartoyo et al. 2019; Rezeki et al. 2023). The collected data was then recorded on observation sheets and tabulated in Ms. Excel.

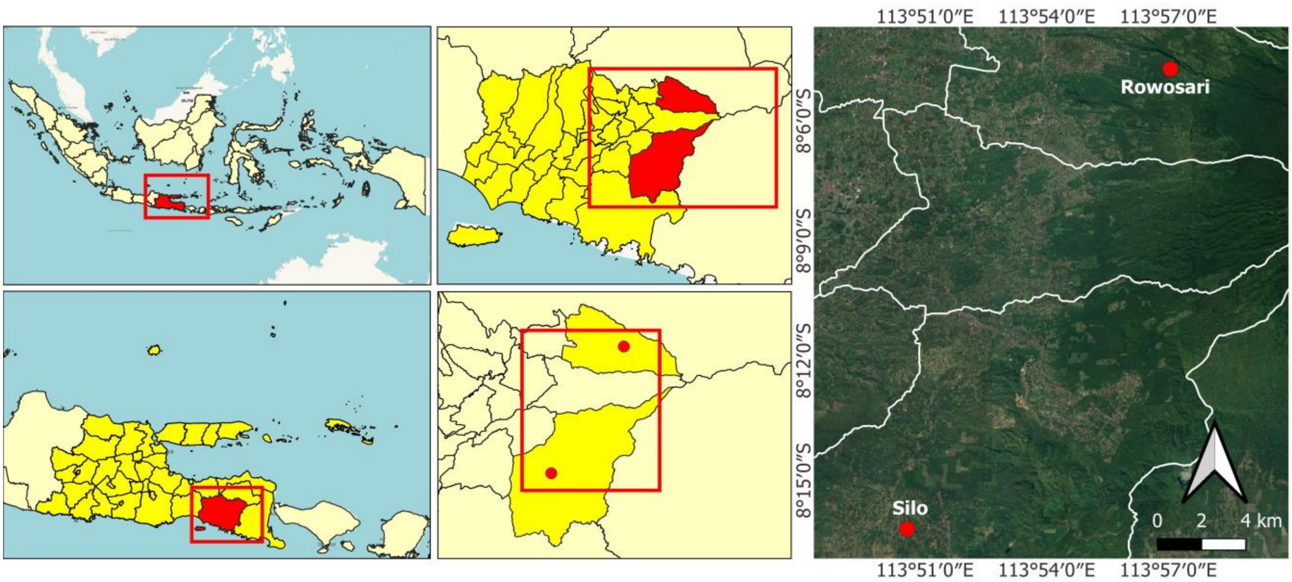

Figure 1. Research locations in two types of coffee-based agroforestry management in Sumberjambe and Silo Sub-districts, Jember District, East Java, Indonesia

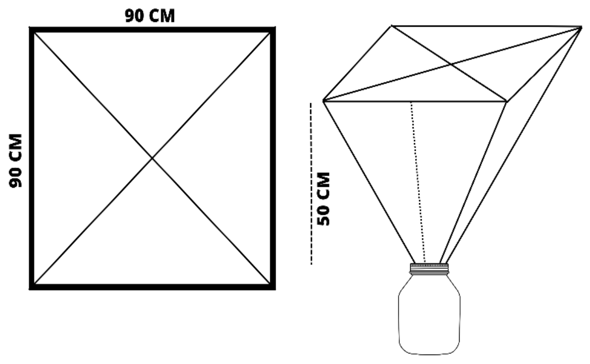

Figure 2. Beating sheet

Data analysis

The research data has been analyzed to understand ant diversity, ant populations, and the influence of vegetation on ants. The data analysis methods used in the study are as follows:

Important Value Index

The importance and position of a species within the observation area can be determined through the Importance Value Index (IVI). The formula that can be used to calculate the Importance Value Index (Khan et al. 2016) is:

$$\text{Density (K)} = \frac{\text{Number of individuals of each species}}{\text{Area of Plot}}$$

$$\text{Relative density (KR)} = \frac{\text{K}}{\text{Total number of all species}} \times 100\%$$

$$\text{Frequency (F)} = \frac{\text{Number of type a species found in a plot}}{\text{Total frequency of all species}}$$

$$\text{Relative Frequency (FR)} = \frac{\text{F}}{\text{Total frequency of all species}} \times 100\%$$

IVI = Relative density (KR) + Relative Frequency (FR)

Shannon-Wiener Species Diversity Index (H')

The diversity of species in region within an agroecosystem area can be determined through the Shannon-Wiener index. The formula used to calculate the Shannon-Wiener index value (Strong 2016) is as follows:

$$H' = \sum \frac{ni}{N} \text{In}\left(\frac{ni}{N}\right)$$

Where:
H' : The Shannon-Wiener index
ni : The number of individuals of the i-th species
N : Total number of individuals of all species

The assessment criteria for the Shannon-Wiener diversity index are:
H'<1 : Low diversity
2<H'<3 : Moderate diversity
H'>3 : High diversity

The Evenness Index (E)

According to (Haneda and Yuniar (2020), the evenness index can be used to calculate the evenness of the abundance of individuals for each species. The formula used to calculate the evenness index (Kvålseth 2015) is as follows:

$$E = \frac{H'}{\text{In S}}$$

Where:
E : Evenness Index
H' : Shannon-Wiener Diversity Index
S : The number of identified species

The assessment criteria for the Evenness Index are:
E>0.6 : High evenness of species
0.3<E<0.6: Moderate evenness of species
E<0.3 : Low evenness of species

The Margalef Species Richness Index (DMg)

The species richness index can determine the species richness within an ecosystem compared to the total number of individuals. The formula used to calculate the Margalef species richness index (Van Loon et al. 2018) is as follows:

$$\text{DMg} = \frac{(s-1)}{\text{In N}}$$

Where:
DMg: Margalef Species Richness Index
S : The number of identified species
N : The total number of individuals of all species

The assessment criteria for the Margalef species richness index are:
Dmg<2.5 : Low level of species richness
2.5<Dmg<4 : Moderate level of species richness
Dmg>4 : High level of species richness

Statistical Difference Test

Statistical tests for determining the significance of the ant inventory results as natural enemies in two types of coffee-based agroforestry management in Jember District. Before conducting the difference test, a normality test was carried out using Shapiro-Wilk. Because the data was not normally distributed, a non-parametric Mann-Whitney test (U-test) difference test analysis was carried out. The Pearson Correlation Test was conducted to determine the extent of vegetation's influence on ants. The output of this test is a correlation coefficient ranging from -1 (indicating a very strong negative influence) to 1 (indicating a very strong positive influence. Normality test, difference test, and correlation test were carried out using SPSS 16.0 software, with a confidence level of 95% or a significance level α = 5% (0.05). Visual graphs like the Canonical Correspondence Analysis (CCA; the input is data on Physical-Environmental conditions and ant populations), Heat MAP, Boxplot and Scatter plot were created using the Matplotlib and Seaborn libraries (Lemenkova 2020).

RESULTS AND DISCUSSION

Ant identification

Based on the research conducted in two types of coffee-based agroforestry, 8 ant genera were found in the Sumberjambe Sub-district and 7 ant genera in the Silo Sub-district. Several genera were exclusively found in one research location (Table 1). Genera such as *Paratrechina*, *Monomorium*, *Oodontomachus* and *Myrmicaria* were solely found in the coffee-based agroforestry of Sumberjambe Sub-district. On the other hand, genera *Camponotus*, *Ponera*, and *Solenopsis* were exclusively found in the coffee-based agroforestry of Silo Sub-district. Additionally, ant genera were found in both research locations: *Crematogaster*, *Tapinoma*, *Lasius*, and *Dolichoderus*.

Some ants found in the research locations play a vital role as predators. Insects capable of serving as natural enemies of pests are referred to as predatory insects. Ants that are predators can prey on pests such as caterpillars, plant hoppers, borers, and whiteflies (Beilhe et al. 2020). Genera *Crematogaster*, *Tapinoma*, *Lasius*, *Dolichoderus*, *Monomorium*, *Odontomachus*, *Paratrechina*, and *Myrmicaria* serve as predatory ants in the coffee-based agroforestry of Sumberjambe Sub-district. Meanwhile, ant genera *Crematogaster*, *Tapinoma*, *Lasius*, *Dolichoderus*, *Camponotus*, *Ponera*, and *Solenopsis* are predatory ants found in the coffee-based agroforestry of Silo Sub-district. Among these, *Lasius* genus, (n=762 individuals), and *Dolichoderus* genus (n=6637 individuals), are the predatory ants found with the highest population in the coffee-based agroforestry of Sumberjambe and Silo Sub-districts, respectively.

Differential test results

The Shapiro-Wilk normality test and the non-parametric U-test were used to determine whether there were significant differences in the number of ants found at the two research locations. Based on the U-test with a confidence level of 95%, it produces a value >0.05; p-value=0.083. This shows that there is no significant difference in the two research locations based on the findings of ants that have the potential to be predators (Figure 3).

Ant diversity

The analysis of ant diversity in coffee-based agroforestry in Silo shows 7 ant genera were identified as predators. The highest density was observed in the *Dolichoderus* genus (Figure 4). The *Dolichoderus* genus is a group of ants from the dolichoderinae subfamily with a petiole with a lower and slightly forward-leaning node, which is clearly visible. The propodeum of the *Dolichoderus* genus has a distinct and protruding projection towards the back. The antennas of these ants consist of 12 segments. This genus accounts for a relative density of 72.58%, whereas the lowest density was found in the *Ponera* and *Solenopsis* genera with a relative density of 0.01%. *Dolichoderus* and *Lasius* genera displayed the highest frequency, representing a relative frequency of 27.273%, while the remaining 6 ant genera, including Tapinoma, showed a low frequency at 9.09%. The genus with the highest IVI was *Dolichoderus*, scoring 99.85%, while *Ponera* and *Solenopsis* genera had the lowest IVI value at 9.10%. A genus with a high IVI signifies dominance, indicating its efficient utilization of the environment compared to other species in the same environment and the influential environmental factors (Table 2).

This study revealed that the genus *Dolichoderus* is the most commonly found ant in coffee-based agroforestry in Silo. Research by Beilhe et al. (2020) and Muhammad et al. (2022) also identified *Dolichoderus* as the dominant ant on the canopy of coffee plantations. *Dolichoderus* ants belong to the Dolichoderinae subfamily and exhibit dominant behavior, thriving in hot and open habitats (De Jesus Santos et al. 2021). This aligns with the conditions observed in the research area of the coffee-based agroforestry in Silo, which has higher temperatures compared to the research area of coffee-based agroforestry in Sumberjambe and is located in an urban area.

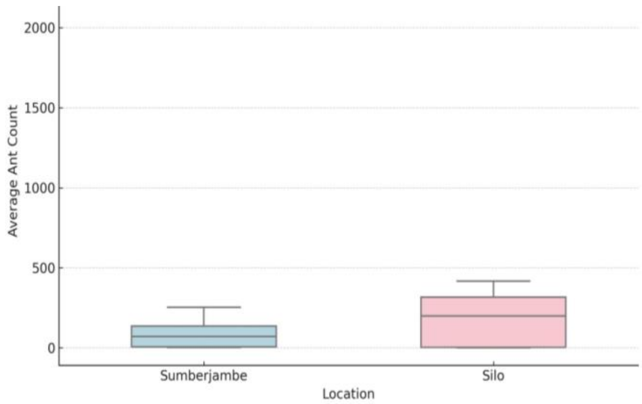

Figure 3. The average ant count between Sumberjambe and Silo locations

Table 1. Results of ant inventory in two types of coffee-based agroforestry management

Genus	Role	References	***n* individuals**	
			Sumberjambe	**Silo**
Crematogaster	Predator	Jiménez et al. (2013)	357	596
Tapinoma	Predator	Escobar-Ramírez (2019)	239	654
Lasius	Predator	Gonthier et al. (2013)	762	1,249
Dolichoderus	Predator	Kar et al. (2022)	564	6,637
Monomorium	Predator	Vega et al. (2015)	19	0
Odontomachus	Predator	Morris and Perfecto (2016)	4	0
Paratrechina	Predator	Trible and Carroll (2014)	182	0
Myrmicaria	Predator	Jauharlina et al. (2021)	16	0
Camponotus	Predator	Infante (2018)	0	7
Ponera	Predator	Vega et al. (2015)	0	1
Solenopsis	Predator	Morris and Perfecto (2016)	0	1

Dolichoderus ant genus competes with coffee berry borers on coffee plants for habitat (Armbrecht and Gallego 2007). *Dolichoderus* ants construct nests and actively operate on various parts of the coffee plant, such as branches, leaves, and coffee berries. This activity prevents coffee berry borers (*Hypothenemus hampei*) from feeding and laying eggs on coffee berries. The presence of ant colonies, especially on coffee berries, deters coffee berry borers from attacking the coffee fruit (Jauharlina et al. 2021).

Based on the analysis of ant diversity in coffee-based agroforestry in Sumberjambe, 8 genera were identified as predators. The highest relative density was observed in the genus Lasius (Figure 5). The *Lasius* genus is a group of ants from the Formicinae subfamily, characterized by having an acidopore on the gaster part. When biting their prey, ants from the *Lasius* genus release formic acid from the acidopore to intensify the pain inflicted on their enemy. The propodeum of this genus is broadly rounded in shape. The body color of the *Lasius* genus is brownish or greyish-black, sometimes bicolored with a gaster lighter than the alitrunk. This genus accounted for 35.56%, while the lowest relative density was found in *Odontomachus* at 0.19%. The highest relative frequency was observed in the genera *Crematogaster*, *Lasius*, and *Dolichoderus*, with a value of 20.00%. In contrast, the lowest relative frequency was found in 4 ant genera: *Tapinoma*, *Odontomachus*, *Paratrechina*, and *Myrmicaria*, with a value of 6.67%. The genus with the highest IVI was *Lasius*, scoring 55.56%, while the lowest IVI was observed in the genus *Odontomachus* with a value of 6.85% (Table 3).

The genus *Lasius* holds the highest IVI value due to its dominance; it thrives in an ecosystem influenced by the available food sources. *Lasius* ants consume dead insects and small living insects and utilize honeydew produced by aphids as their food source (Kar et al. 2022). The abundance of *Lasius* genus found in the coffee-based agroforestry in Sumberjambe Sub-district is attributed to honeydew as a food source. *Lasius* genus tends to opportunistically feed on food containing glucose (Detrain and Prieur 2014).

Mutualistic symbiosis occurs between ants and aphids. Ants from the Genus *Lasius* are attracted to the honeydew produced by aphids (Homoptera: Pseudococcidae) (Depa et al. 2020). *Lasius* ants rely on the honeydew produced by aphids as their energy source, and Aphids benefit from the ants' protection from other predatory insects. However, research by (Blanchard et al. 2021) suggests that *Lasius* ants may prey on aphids that produce limited honeydew. The *Lasius* genus tends to hunt weak or isolated aphids from their group. When food sources such as insects and honeydew are scarce, *Lasius* ants may prey on aphids to maintain their protein supply and carbohydrates (Endo and Itino 2013; Depa et al. 2020).

The calculation results of the ant species Diversity Index (H') in coffee-based agroforestry in Silo show 0.88, while in Sumberjambe, it is 1.56, which is categorized as low. These low results indicate an unstable ecosystem in these areas due to the dominance of a particular ant genus with uneven distribution, found only in specific points. The dominant ant genus in the coffee-based agroforestry in Silo is *Dolichoderus*, whereas in the Sumberjambe area, *Lasius* is the dominant genus. The dominant ant genus was found at three research points in abundance (Tables 2 and 3).

Table 2. The result of ant diversity analysis in coffee-based agroforestry in Silo

Ant genus	RD (%)	RF (%)	IVI (%)
Dolichoderus	72.58	27.27	99.85
Lasius	13.66	27.27	40.93
Tapinoma	7.15	9.09	16.24
Crematogaster	6.52	9.09	15.61
Camponotus	0.08	9.09	9.17
Ponera	0.01	9.09	9.10
Solenopsis	0.01	9.09	9.10

Note: RD: Relative Density, RF: Relative Frequency, IVI: Importance Value Index

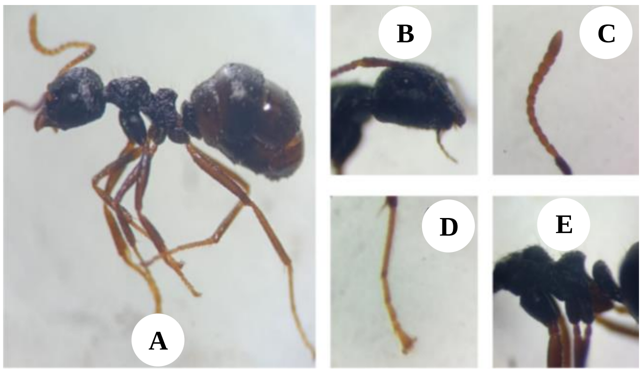

Figure 4. A. The entire body, B. The head, C. The antennae, D. The legs, E. The alitrunk (mesosoma) of the ant genus *Dolichoderus* found in the coffee-based agroforestry land in Silo

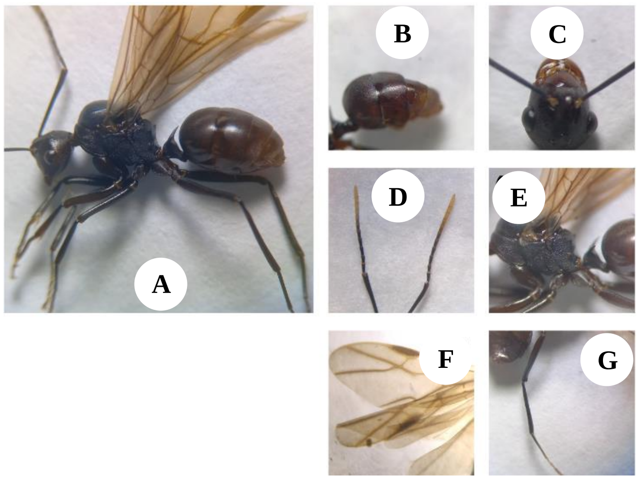

Figure 5. *Lasius* genus ants found in the coffee-based agroforestry land in Sumberjambe. A. The entire body, B. Gaster, C. Mandible, D. Antennae, E. Alitrunk (mesosoma), F. Wing, G. Leg

The Evenness Index (E) value measures the balance between different communities influenced by the number of species within a community (Díaz-García et al. 2017). The species evenness index in coffee-based agroforestry in Sumberjambe Sub-district has a value of 0.75, considered high, while in Silo, it has a value of 0.45, indicating moderate evenness. A high species evenness index indicates an even distribution of species within agroforestry, while a low index suggests the presence of dominant species in a community (Zuo et al. 2021). The evenness index in Silo is higher than in Sumberjambe because each obtained genus has a relatively similar or even number. The evenness index in Sumberjambe's coffee-based agroforestry is moderate due to a high or dominant number of *Dolichoderus* genus; the environmental, physical, and physiological aspects influence ant populations in a habitat. Also, several factors, such as nesting sites, light availability, and soil conditions, affect ant needs. Therefore, unsuitable environments for ant nesting affect ant populations in a habitat (Subedi et al. 2021).

The Richness Index using the Margalef Index shows a value of 0.66 in the coffee-based agroforestry in Silo and 0.91 in the coffee-based agroforestry in Sumberjambe, both categorized as low. These ant species richness values correspond to the number of ant genera found in each research location. The number of ant genera found is directly proportional to the richness value with the Margalef Index (Alvareza et al. 2020). In Silo, a total of 7 ant genera were found, whereas in Sumberjambe, 8 ant genera were found.

Bray Curtis Index

The dendrogram created based on Bray-Curtis dissimilarity provides a visual representation of the compositional differences between two locations: Sumberjambe and Silo (Figure 6). The index value is close to 0, then the level of similarity is low and conversely, if the index value is close to 1, the level of similarity is high. The vertical height of the branches (or links) connecting the two locations indicates a dissimilarity level, with greater height indicating greater differences. In this case, the significant height of the link indicates a clear compositional difference between the species present in Sumberjambe and Silo. This suggests that although there may be some shared species between the two sites, the abundance or proportion of these species is significantly different, resulting in distinct ecological compositions at each location.

Vegetation diversity

Tree species vegetation

The Highest Importance Value Index in tree species vegetation in coffee-based agroforestry in Silo is found in the sengon tree species, amounting to 209.37%. This is based on a relative density of 71.68%, a relative frequency of 42.86%, and a relative dominance of 94.38% (Table 5). Tree species with the highest IVI play a crucial role in a community. The main products from the initial agroforestry land are wood from Albizia plants and coffee plants. *Albizia* is a legume tree species known to enhance nitrogen in the soil (Mardaraj et al. 2023). Nitrogen input can come from the decomposition of organic matter, one of which can originate from plant litter. The availability of organic matter in the soil enhances soil fauna activity (Frouz 2018). High organic matter increases ant populations and protects ant colonies from environmental pressures. Ants extract nutrients from organic soil matter, influencing ant abundance (Herwina et al. 2020).

Coffee-based agroforestry land in Silo is located near residential areas. The abundance of ants in agroforestry land is related to food availability and their ability to survive in an environment disturbed by human activities. Based on the research results, ants can live and thrive in habitats with human activities. Ant abundance is found to be higher in coffee-based agroforestry land in Silo compared to coffee-based agroforestry land in Sumberjambe. Ant communities in unstable land and increasing air temperature exhibited lower species diversity and more Dolichoderinae (a subfamily of highly active ants). This aligns with research findings that indicate the *Dolichoderus* genus from the Dolichoderinae subfamily is commonly found in coffee-based agroforestry land in Silo.

The highest Importance Value Index in the vegetation of tree species in coffee-based agroforestry in Sumberjambe is found in the pine tree species, amounting to 189.15%. This is based on a relative density of 40%, a relative frequency of 50%, and a relative dominance of 99.15% (see Table 6). Pine trees are utilized as a source of wood, and their resin is extracted without the need to cut down the trees. Pine trees provide shade for the coffee plants in the research area. This will affect the microclimate, influencing the living organisms beneath the shade of the pine trees.

Physical and chemical factors influence the abundance of ants in coffee-based agroforestry in the environment. The research site in Sumberjambe has optimal temperature conditions, as it is not too hot or cold and sufficient humidity that can support ant populations. A study by Agathokleous et al. (2020) states that ants of the genus Lasius are often found in shaded areas near their food sources. The genus Lasius carries out its activities above plants at temperatures that are not too hot. This is consistent with research findings identifying many *Lasius* genus ants in coffee-based agroforestry in Sumberjambe.

Table 3. The result of ant diversity analysis in coffee-based agroforestry in Sumberjambe

Ant genus	RD (%)	RF (%)	IVI (%)
Lasius	35.56	20.00	55.56
Dolichoderus	26.32	20.00	46.32
Crematogaster	16.66	20.00	36.66
Tapinoma	11.15	6.67	17.82
Paratrechina	8.49	6.67	15.16
Monomorium	0.89	13.33	14.22
Myrmicaria	0.75	6.67	7.41
Odontomachus	0.19	6.67	6.85

Note: RD: Relative Density, F: Frequency, RF: Relative Frequency, IVI: Importance Value Index

Table 4. The result of the analysis of ant diversity data in coffee-based agroforestry

Plant	H'		E		Dmg	
	Value	Category	Value	Category	Value	Category
Coffee-Based Agroforestry in Silo	0.88	Low	0.45	Moderate	0.66	Low
Coffee-Based Agroforestry in Sumberjambe	1.56	Low	0.75	High	0.91	Low

Note: H': Species Diversity Index, E: Species Evenness Index, Dmg: Species Richness Index

Table 5. Results of the diversity analysis of tree species vegetation in coffee-based agroforestry in Silo

Local name	Scientific name	RD (%)	RF (%)	RD (%)	IMP (%)
Sengon	*Albizia chinensis*	71.68	42.86	94.83	209.37
Mahoni	*Swietenia mahagoni*	1.77	14.29	2.51	18.57
Kopi robusta	*Coffea canephora*	26.55	42.86	2.65	72.06

Note: RD: Relative Density, RF: Relative Frequency, RD: Relative Dominance, IMP: Importance Value Index

Table 6. The analysis results of the diversity of tree species vegetation in coffee-based agroforestry in Sumberjambe

Local name	Scientific name	RD (%)	RF (%)	RD (%)	IMP (%)
Pinus	*Pinus merkusii*	40.00	50.00	99.15	189.15
Kopi robusta	*Coffea canephora*	60.00	50.00	0.85	110.85

Note: RR: Relative Density, RF: Relative Frequency, RD: Relative Dominance, IMP: Importance Value Index

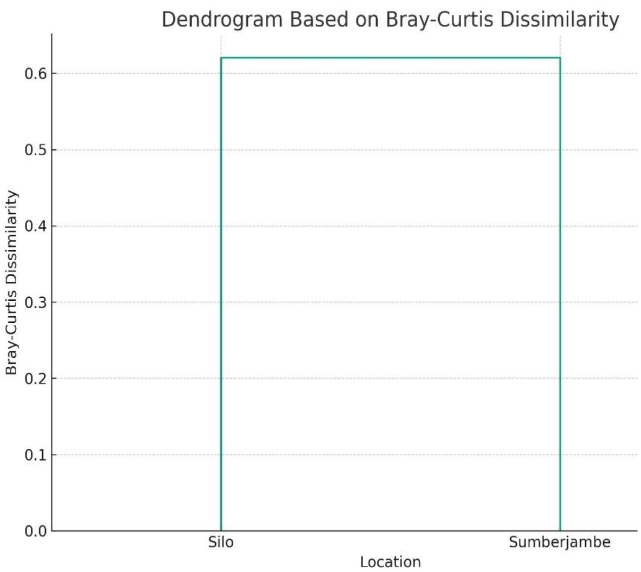

Figure 6. Dendrogram of 2 locations for Bray-Curtis Dissimilarity

The species diversity index in tree vegetation in coffee-based agroforestry land in Silo shows a value of 0.66. Coffee-based agroforestry land in Sumberjambe shows a value of 0.67, which is classified as low. The diversity index describes the population condition of organisms in a community to facilitate the analysis of the number of individuals of each species. Competition between ants and other more dominant insects will impact the diversity of ants in the research area. More dominant ant genera will influence colony strength as they can control a significant portion of the available food sources (Triyogo et al. 2020).

The species evenness index in tree vegetation in coffee-based agroforestry land in Sumberjambe shows a value of 0.97, which is considered high, while in coffee-based agroforestry land in Silo, it shows a value of 0.60, which is considered moderate. The evenness index indicates uniformity and equality among species, so a high evenness value suggests that the community is stable. The evenness index can be used to indicate dominant symptoms among species in a community (Amaya-Espinel et al. 2019). The pine tree is the dominant tree species in the coffee-based agroforestry land in Sumberjambe.

The calculation of the richness index using the Margalef index in coffee-based agroforestry land in Silo shows a value of 0.42. In contrast, coffee-based agroforestry land in Sumberjambe shows a value of 0.22, both of which are classified as low. This index provides a value that reflects the diversity of genera in the community by considering the number of genera found. The wealth index is classified as low because only 3 tree species were found in coffee-based agroforestry in Silo and 2 tree species in coffee-based agroforestry in Sumberjambe.

The influence of vegetation diversity on ant diversity

The table illustrates the Pearson correlation coefficients between the counts of different ant genera and vegetation types in Silo, indicating a range of relationships (Table 8). High correlation coefficients, such as 0.9960 between *Tapinoma* ants and *Albizia*, suggest a strong and a significance positive association (p-value=0.0467). This preliminary analysis points towards potential patterns that warrant further investigation with larger datasets. The Pearson correlation bar graph illustrates the relationship between ant genera and specific plant types (Figure 7). A positive correlation indicates that when the presence or quantity of a particular plant increases, the presence of a specific ant genus also tends to increase, and vice versa. On the other hand, some other ant genera, such as *Dolichoderus*, show a positive correlation with Mahogany plants. In contrast, *Tapinoma* shows a negative correlation with Mahogany, meaning that as the presence of this plant increases, the presence of ants from that genus tends to decrease. This provides insights into the potential interactions between ants and plants in their habitat.

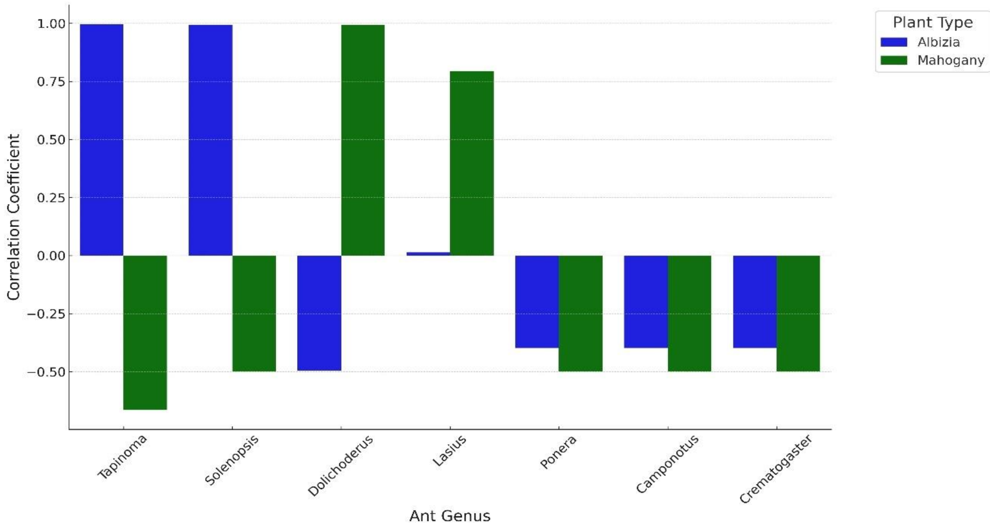

Figure 7. The Pearson correlation results depict the relationship between plants and ants. Only the Silo location is valid in providing an overview of the influence of vegetation on ant communities

Table 7. Results of the data analysis on the diversity of tree species vegetation in coffee-based agroforestry

Plant	H'		E		Dmg	
	Value	Category	Value	Category	Value	Category
Coffee-Based Agroforestry in Silo	0.66	Low	0.60	Moderate	0.42	Low
Coffee-Based Agroforestry in Sumberjambe	0.67	Low	0.97	High	0.22	Low

Note: H': Species Diversity Index, E: Species Evenness Index, Dmg: Species Richness Index

Table 8. Pearson correlation table between types of vegetation and ant genus at Silo. Significant interaction indicated by asterisk (*)

Ant genus	Plant type	Correlation coefficient	P-value
Dolichoderus	Albizia	-0.4949	0.6704
Lasius	Albizia	0.0134	0.9914
Tapinoma	Albizia	0.9960	0.0467*
Camponotus	Albizia	-0.3974	0.7399
Ponera	Albizia	-0.3974	0.7399
Crematogaster	Albizia	-0.3974	0.7399
Solenopsis	Albizia	0.9934	0.0432*
Dolichoderus	Mahogany	0.9927	0.0469*
Lasius	Mahogany	0.7949	0.4151
Tapinoma	Mahogany	-0.6651	0.5368
Camponotus	Mahogany	-0.5000	0.6667
Ponera	Mahogany	-0.5000	0.6667
Crematogaster	Mahogany	-0.5000	0.6667
Solenopsis	Mahogany	-0.5000	0.6667

In the heatmap, we can observe the relationship between various ant genera and specific plant types. Warmer colors (towards red) indicate a strong positive relationship, suggesting that the presence or quantity of a particular plant and a specific ant genus tend to increase or decrease together (Figure 8). Conversely, cooler colors (towards blue) indicate a negative relationship, meaning that the other species tends to decrease when one species increases. The ant genera *Tapinoma* and *Solenopsis* show a very strong positive correlation with *Albizia* plants, indicating that they are likely to be found together in locations with similar vegetation. However, some other combinations show weaker or close-to-zero correlations, suggesting that the number of vegetation species does not strongly influence their presence or quantity.

The boxplot depicts the results of Canonical Correspondence Analysis (CCA) for Ant Genera and Environmental Parameters (Figure 9). The Silo location shows that the CCA projection distribution for ant findings tends to be lower compared to the Sumberjambe location. This indicates differences in the response of ant findings to environmental factors between these two locations. The variability in ant findings in Silo may be more influenced by specific environmental factors compared to Sumberjambe, or vice versa. The scattered points on the boxplot indicate individual variations in the data, with some points outside the interquartile range, suggesting the possibility of outliers or significant variations in the obtained ants concerning environmental factors.

The visualization of Canonical Correspondence Analysis (CCA) on a scatter plot shows the interaction between the obtained ants and environmental factors in two locations, Silo and Sumberjambe (Figure 10). Environmental vectors, such as "Humidity (%)," "Light Intensity," and "Temperature (°C)," indicate how each factor influences ants. The length and direction of vectors indicate the strength and type of relationship between environmental factors and ants. Silo and Sumberjambe show different responses to environmental factors, with colored areas indicating ants' density based on environmental factors in each location. Humidity and Light Intensity seem to influence ants in Silo positively. However, conversely, light intensity appears to have a negative impact on ants in both locations.

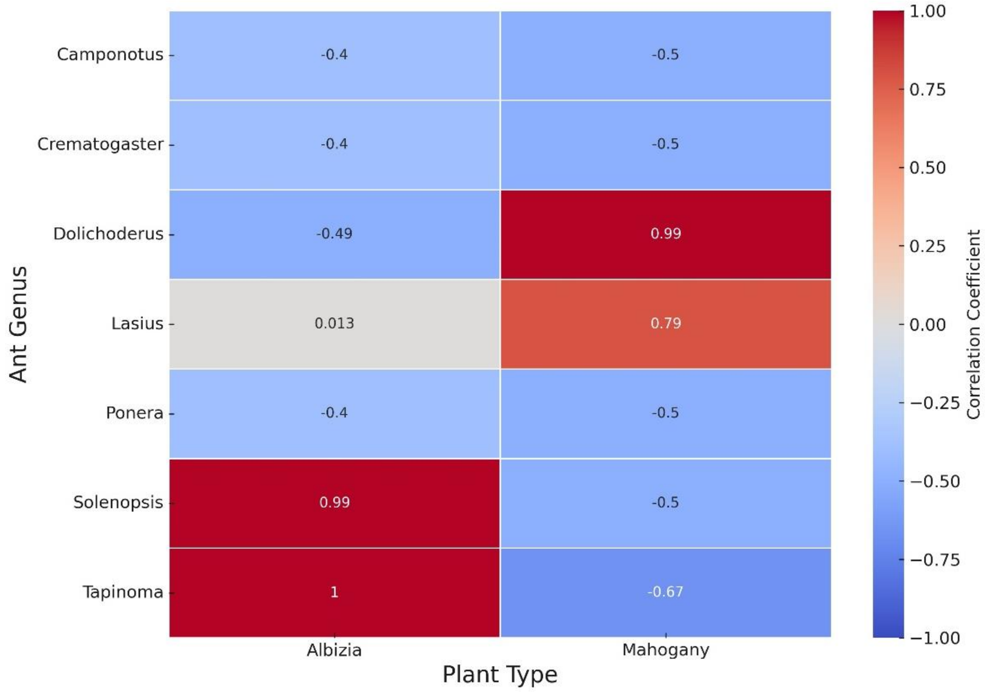

Figure 8. Heatmap chart of interactions between plants and ant genera. Note: Warm colors (towards red) indicate a strong positive relationship. Cooler colors (towards blue) indicate increasingly negative interaction relationships

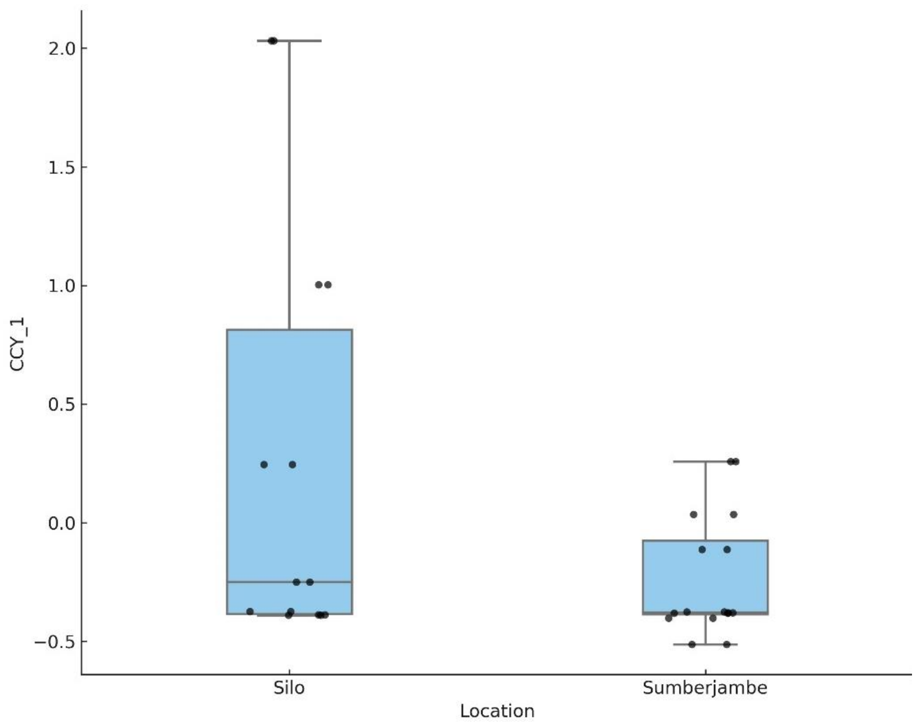

Figure 9. Boxplot chart of Canonical Correspondence Analysis (CCA) for 2 locations

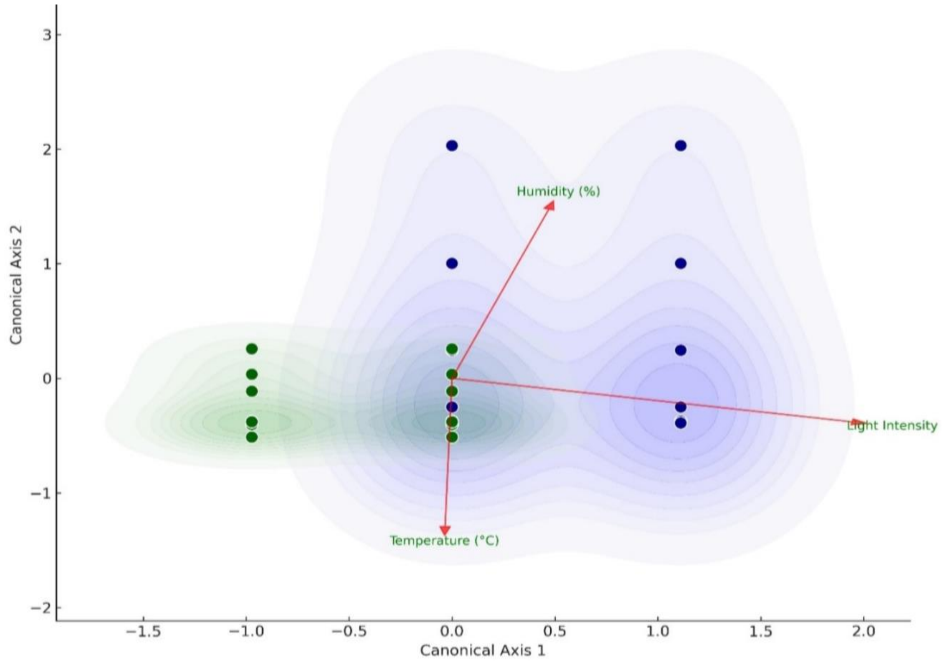

Figure 10. Scatter plot of Canonical Correspondence Analysis (CCA) Chart. Note: Blue: Sumberjambe, Green: Silo

In conclusion, the research on ant diversity in two types of coffee-based agroforestry in Sumberjambe and Silo provides valuable insights. The findings indicate differences in ant genera between locations, with some genera exclusively found in one district. Certain ant genera play a role as predators, notably Dolichoderus, which protects coffee plants from pests. The differential test between the two locations shows no significant difference in the number of predator ants. Ant diversity analysis reveals Dolichoderus as the dominant genus in Silo, while Lasius dominates in Sumberjambe. Both locations exhibit low species diversity, signaling an unstable ecosystem.

Ant diversity indexes indicate ecosystem instability in both locations. Correlation analysis between ant genera and plant types offers insights into their potential interactions. Canonical Correspondence Analysis (CCA) highlights different responses of ants to environmental factors in Silo and Sumberjambe. In summary, this research provides important information on ant diversity, predator roles, and interactions with the environment in coffee-based agroforestry. Understanding these dynamics is crucial for sustainable farming practices, pest control, and maintaining ecological balance in agroforestry systems. Further research and conservation efforts can leverage these findings to enhance resilience and productivity in coffee-based agroforestry systems.

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REFERENCES

Agathokleous E, Feng Z, Oksanen E, Sicard P, Wang Q, Saitanis CJ, Araminiene V, Blande JD, Hayes F, Calatayud V, Domingos M, Veresoglou SD, Peñuelas J, Wardle DA, De Marco A, Li Z, Harmens H, Yuan X, Vitale M, Paoletti E. 2020. Ozone affects plant, insect, and soil microbial communities: A threat to terrestrial ecosystems and biodiversity. Sci Adv 6 (33): eabc1176. DOI: 10.1126/sciadv.abc1176.

Alvareza M, Nugraha FAD, Putri ILE, Satria R. 2020. Diversity of ground-foraging ants (Hymenoptera: Formicidae) in Bukit Kasang and Lubuk Bonta, Padang Pariaman District, West Sumatra. Jurnal Biologi Universitas Andalas 8: 54-60. DOI: 10.25077/jbioua.8.2.54-60.2020. [Indonesian]

Amaya-Espinel JD, Hostetler M, Henríquez C, Bonacic C. 2019. The influence of building density on Neotropical bird communities found in small urban parks. Landsc Urban Plan 190: 103578. DOI: 10.1016/j.landurbplan.2019.05.009.

Armbrecht I, Gallego MC. 2007. Testing ant predation on the coffee berry borer in shaded and sun coffee plantations in Colombia. Entomol Exp Appl 124 (3): 261-267. DOI: 10.1111/j.1570-7458.2007.00574x.

Beilhe LB, Roudine S, Perez JAQ, Allinne C, Daout D, Mauxion R, Carval D. 2020. Pest-regulating networks of the coffee berry borer (*Hypothenemus hampei*) in agroforestry systems. Crop Prot 131: 105036. DOI: 10.1016/j.cropro.2019.105036.

Blanchard S, Van Offelen J, Verheggen F, Detrain C. 2021. Towards more intimacy: Moderate elevation of temperature drives increases in foraging and mutualistic interactions between *Lasius niger* and *Aphis fabae*. Ecol Entomol 46 (2): 406-418. DOI: 10.1111/een.12982.

Bolton B. 1994. Identification guide to the ant genera of the world. Harvard University Press, Cambridge.

Byrareddy V, Kouadio L, Mushtaq S, Stone R. 2019. Sustainable production of robusta coffee under a changing climate: A 10-year monitoring of fertilizer management in coffee farms in Vietnam and Indonesia. Agronomy 9 (9): 499. DOI: 10.3390/agronomy9090499.

Collingwood CA. 1979. The Formicidae (Hymenoptera) of Fennoscandia and Denmark. Scandinavian Science Press, Klampenborg.

De Jesus Santos R, Dodonov P, Delabie JHC. 2021. Effects of habitat conversion on ant functional groups: A global review. Sociobiology 68 (2): e6071. DOI: 10.13102/sociobiologyv68i2.6071.

Depa Ł, Kaszyca-Taszakowska N, Taszakowski A, Kanturski M. 2020. Ant-induced evolutionary patterns in aphids. Biol Rev Camb Philos Soc 95 (6): 1574-1589. DOI: 10.1111/brv.12629.

Detrain C, Prieur J. 2014. Sensitivity and feeding efficiency of the black garden ant *Lasius niger* to sugar resources. J Insect Physiol 64: 74-80. DOI: 10.1016/j.jinsphys.2014.03.010.

Díaz-García JM, Pineda E, López-Barrera F, Moreno CE. 2017. Amphibian species and functional diversity as indicators of restoration success in tropical montane forest. Biodivers Conserv 26: 2569-2589. DOI: 10.1007/s10531-017-1372-2.

Endo S, Itino T. 2013. Myrmecophilous aphids produce cuticular hydrocarbons that resemble those of their tending ants. Popul Ecol 55 (1): 27-34. DOI: 10.1007/s10144-012-0355-0.

Escobar-Ramírez S, Grass I, Armbrecht I, Tscharntke T. 2019. Biological control of the coffee berry borer: Main natural enemies, control success, and landscape influence. Biol control 136: 103992. DOI: 10.1016/j.biocontrol.2019.05.011.

Frouz J. 2018. Effects of soil macro- and mesofauna on litter decomposition and soil organic matter stabilization. Geoderma 332: 161-172. DOI: 10.1016/j.geoderma.2017.08.039.

Gonthier DJ, Ennis KK, Philpott SM, Vandermeer J, Perfecto I. 2013. Ants defend coffee from berry borer colonization. BioControl 58: 815-820. DOI: 10.1007/s10526-013-9541-z.

Hartoyo APP, Prasetyo LB, Siregar IZ, Supriyanto, Theilade I, Siregar UJ. 2019. Carbon stock assessment using forest canopy density mapper in agroforestry land in Berau, East Kalimantan, Indonesia. Biodiversitas 20 (9): 2661-2676. DOI: 10.13057/biodiv/d200931.

Herwina H, Mairawita, Yulvita L, Putri D, Satria R, Janra MN, Yaherwandi, Sakamaki Y. 2020. Ant species composition (Hymenoptera: Formicidae) at a highland agricultural area for wheat and potato in Alahan Panjang, West Sumatera. IOP Conf Ser: Earth Environ Sci 515: 012018. DOI: 10.1088/1755-1315/515/1/012018.

Infante F. 2018. Pest management strategies against the coffee berry borer (Coleoptera: Curculionidae: Scolytinae). J Agric Food Chem 66 (21): 5275-5280. DOI: 10.1021/acs.jafc.7b04875.

Jauharlina J, Husni H, Halimursyadah H, Rizali A, Febrian TA. 2021. Diversity of ants (Hymenoptera:Formicidae) in organic and conventional Arabica coffee plantations in Aceh Tengah Regency, Sumatra, Indonesia. IOP Conf Ser Earth Environ Sci 667: 012036. DOI: 10.1088/1755-1315/667/1/012036.

Jiménez-Soto E, Cruz-Rodríguez JA, Vandermeer J, Perfecto I. 2013. *Hypothenemus hampei* (Coleoptera: Curculionidae) and its interactions with *Azteca instabilis* and *Pheidole synanthropica* (Hymenoptera: Formicidae) in a shade coffee agroecosystem. Environ Entomol 42 (5): 915-924. DOI: 10.1603/en12202.

Kar S, Sirin D, Akyildiz G, Sakaci Z, Talay S, Camlitepe Y. 2022. Predation of ant species *Lasius alienus* on tick eggs: Impacts of egg wax coating and tick species. Sci Rep 12 (1): 14773. DOI: 10.1038/s41598-022-19300-7.

Khan L, Amin N, Hussain Z, Luqman, Shah K, Khan MA, Ilyas M, Ullah Z, Khan MI. 2016. Importance value indices of various weeds and their management in turf grass. Pure Appl Biol 5 (4): 804-814. DOI: 10.19045/bspab.2016.50101.

Kvålseth TO. 2015. Evenness indices once again: Critical analysis of properties. SpringerPlus 4: 232. DOI: 10.1186/s40064-015-0944-4.

Lemenkova P. 2020. Python libraries matplotlib, seaborn and pandas for visualization geo-spatial datasets generated by QGIS. Sci Ann Alexandru Ioan Cuza Univ Iași 64 (1): 13-32. DOI: 10.15551/scigeo.v64i1.386.

Mardaraj PC, Pirie TJ, Sethy J, Behera S. 2023. Community stance towards sloth bear (*Melursus ursinus*) conservation in Odisha, India. Biodiversitas 24 (5): 2521-2526. DOI: 10.13057/biodiv/d240503.

Morris JR, Perfecto I. 2016. Testing the potential for ant predation of immature coffee berry borer (*Hypothenemus hampei*) life stages. Agric Ecosyst Environ 233: 224-228. DOI: 10.1016/j.agee.2016.09.018.

Morris JR, Vandermeer J, Perfecto I. 2015. A keystone ant species provides robust biological control of the coffee berry borer under varying pest densities. PLoS One 10 (11): 1428. DOI: 10.1371/journal.pone.0142850.

Muhammad FN, Rizali A, Rahardjo BT. 2022. Diversity and species composition of ants at coffee agroforestry systems in East Java, Indonesia: Effect of habitat condition and landscape composition. Biodivers J 23(7): 3318-3326. DOI:10.13057/biodiv/d230702.

Offenberg J. 2015. Ants as tools in sustainable agriculture. J Appl Ecol 52 (5): 1197-1205. DOI: 10.1111/1365-2664.12496.

Oliveira CM, Auad AM, Mendes SM, Frizzas MR. 2013. Economic impact of exotic insect pests in Brazilian agriculture. J Appl Entomol 137 (1-2): 1-15. DOI: 10.1111/jen.12018.

Panggabean YBS, Arsyad M, Mahyuddin, Nasaruddin. 2021. Coffee farming business development: E-commerce technology utilization. IOP Conf Ser: Earth Environ Sci 807: 032011. DOI: 10.1088/1755-1315/807/3/032011.

Rezeki A, Hatta GM, Arifin YF, Yunita R. 2023. Ecology of endemic primate Proboscis monkeys at Curiak Island Area, South Kalimantan, Indonesia. Jurnal Multidisiplin Madani 3 (3): 552-566. DOI: 10.55927/mudimav3i3.2459.

Saleh A, Armaniar, Ahmad AH. 2020. Strategies for controlling cocoa pod borer, *Conopomorpha cramerella* Snell., on cocoa farmers in Langkat District, North Sumatra, Indonesia. In: Ma W, Prastowo S (eds). Advances in Biological Sciences Research; Proceedings of the International Conference and the 10th Congress of the Entomological Society of Indonesia (ICCESI 2019). The Entomological Society of Indonesia (ESI), Bali, 6-9 October 2019. DOI: 10.2991/absr.k.200513.034.

Sanabria C, Lavelle P, Fonte SJ. 2014. Ants as indicators of soil-based ecosystem services in agroecosystems of the Colombian Llanos. Appl Soil Ecol 84: 24-30. DOI: 10.1016/j.apsoil.2014.07.001.

Strong WL. 2016. Biased richness and evenness relationships within Shannon-Wiener Index values. Ecol Indic 67: 703-713. DOI: 10.1016/j.ecolind.2016.03.043.

Subedi IP, Budha PB, Kunwar RM, Charmakar S, Ulak S, Pradhan DK, Pokharel YP, Velayudhan ST, Sathyapala S, Animon I. 2021. Diversity and distribution of forest ants (Hymenoptera: Formicidae) in nepal: Implications for sustainable forest management. Insects 12 (12): 1128. DOI: 10.3390/insects12121128.

Thurman JH, Northfield TD, Snyder WE. 2019. Weaver ants provide ecosystem services to tropical tree crops. Front Ecol Evol 7: 120. DOI: 10.3389/fevo.2019.00120.

Trible W, Carroll R. 2014. Manipulating tropical fire ants to reduce the coffee berry borer. Ecol Entomol 39: 603-609. DOI: 10.1111/een.12139.

Triyogo A, Budiadi, Widyastuti SM, Subrata SA, Budi SS. 2020. Abundance of ants (Hymenoptera: Formicidae) and the functional groups in two different habitats. Biodiversitas 21 (5): 2079-2087. DOI: 10.13057/biodiv/d210535.

Van Loon WMGM, Walvoort DJJ, van Hoey G, Vina-Herbon C, Blandon A, Pesch R, Schmitt P, Scholle J, Heyer K, Lavaleye M, Phillips G, Duineveld GCA, Blomqvist M. 2018. A regional benthic fauna assessment method for the Southern North Sea using Margalef diversity and reference value modelling. Ecol Indic 89: 667-679. DOI: 10.1016/j.ecolind.2017.09.029.

Vega FE, Infante F, Johnson AJ. 2015. The genus *Hypothenemus*, with emphasis on *H. hampei*, the coffee berry borer. In Vega FE, Hofstetter RW (eds). Bark Beetles: Biology and Ecology of Native and Invasive Species. Academic Press, Cambridge, Massachusetts. DOI: 10.1016/B978-0-12-417156-5.00011-3.

Zuo J, Zu M, Liu L, Song X, Yuan Y. 2021. Composition and diversity of bacterial communities in the rhizosphere of the Chinese medicinal herb Dendrobium. BMC Plant Biol 21: 127. DOI: 10.1186/s12870-021-02893-y.