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The effect of understory plants on pollinators visitation in coffee plantations: Case study of coffee plantations in West Bandung District, West Java, Indonesia

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Abstract. *Withaningsih S, Andari CD, Parikesit, Fitriani N. 2018. The effect of understory plants on pollinators visitation in coffee plantations: Case study of coffee plantations in West Bandung District, West Java, Indonesia. Biodiversitas 19: 604-612.* West Java is one of the excellent producers of the most expensive coffee in the world (Kopi Luwak). Coffee (*Coffea* spp.) is one of the crops that require insect pollination for fruit formation. Coffee production in Indonesia is declining in recent years despite the expansion of coffee cultivation area that increases by 2-5 times. The decline in coffee production has been associated with fewer visitations of pollinator insects. Visitations of pollinator insects can improve the quality and quantity of coffee, mainly from the abundance and diversity of pollinator insect. Abundance and diversity of pollinator insects can be improved by to providing them with flowering plants such as understory plants. This study aimed to prove the effect of the existence of flowering plants on the visitation of pollinator insects. Pollinator insects visiting coffee flowers were observed with an observation method in two observation units. The first unit was the location with understory plants while the second was the location without understory plants. The results showed that the abundance of pollinator insects visiting coffee flowers in unit 1 was significantly (P<0.05) higher than that in unit 2. However, the diversity of pollinator insects between the two locations did not differ significantly (P> 0.05).

Keywords: Abundance, coffee, insect pollinators, diversity, understory plants, visitation

INTRODUCTION

As the third largest coffee producing country in the world after Brazil and Vietnam (Hartono 2013), Indonesia has a one-of-a-kind coffee labeled as the unique and most expensive coffee in the world: Kopi Luwak. Coffee is one of the most important estate crops included as the world's most valuable export commodities (Ricketts et al. 2004). In developing countries, coffee is the second most traded commodity after oil (Munyuli 2014).

Although coffee cultivation areas in Indonesia have increased by two to fivefold in the last 41 years, the coffee yield has fallen by 20-50% (Roubik 2002). The decrease of coffee yield, according to Roubik, is related to the decrease of pollinator insects visitation. More than 70% of angiosperms plants are pollinated by insects, including coffee (Hoffman 2005). The visits of pollinator insects on coffee flowers can influence the formation and duration of coffee and irregularities in coffee beans (Manrique and Thiman 2002; Klein et al. 2003; Ricketts et al. 2004; Olschewski et al. 2006; Veddeler et al. 2008; Classen et al. 2014; Tavares et al. 2014).The significant increase in the diversity and abundance of coffee flower visitor insects (<0) is associated with yield, gross weight, and net income of coffee (Manyuli 2014). Ebeling et al. (2008) found that pollinator insect visits increased linearly with the increase of abundance and species diversity of the flowering plants. The abundance of flowering plants will provide the resources for food, and their diversity will offer better pollen and nectar resources.

Plantation land-use tends to have low abundance and diversity of plant species, especially for monoculture plantations. The types of plants that potentially can increase the abundance and diversity of large estates such as coffee plantations are flowering plants with understories commonly considered as weeds. These plants are generally in the forms of grasses, herbs, and shrubs, which are annual, biennial or perennial, with solitary or cluster life forms, upright, or vine-like form (Althorick 2005). According to Mustakim et al. (2004), the understory plants may serve as microhabitats to attract pollinator insects.

This study aimed to see the effect of understory plants on the visitation of coffee flower insects. The number of pollinator insect visits in the two types of gardens (with or without understory plants) was recorded and compared in terms of abundance and variety of species.

MATERIALS AND METHODS

The research was carried out in one of the coffee plantations in West Java producing Kopi Luwak: coffee plantation under the management of Perhutani Resort Pemangkuan Hutan (RPH) Lembang, West Bandung

District, West Java, Indonesia. Administratively, the research area is included in Jayagiri Village, Lembang Sub-district, West Bandung District, West Java, Indonesia (Figure 1).

Two stages of research were conducted in this study, i.e. the site survey stage and the intensive stage. In the site survey stage, research location was selected, and observation units were determined. The intensive stage was carried out at the observation units that were previously determined in the location survey stage, i.e., in the coffee plantation with understory plants (unit 1) and the coffee plantation without understory plants (the understory plants were cleared) (unit 2). The intensive phase consisted of the selection of observation plots, observation of pollinating insects, and measurements of the understory plants. In each observation unit, five plots of 10 m x 10 m size (Marshall et al. 1994) were measured by *random sampling* (Wheather et al. 2011).

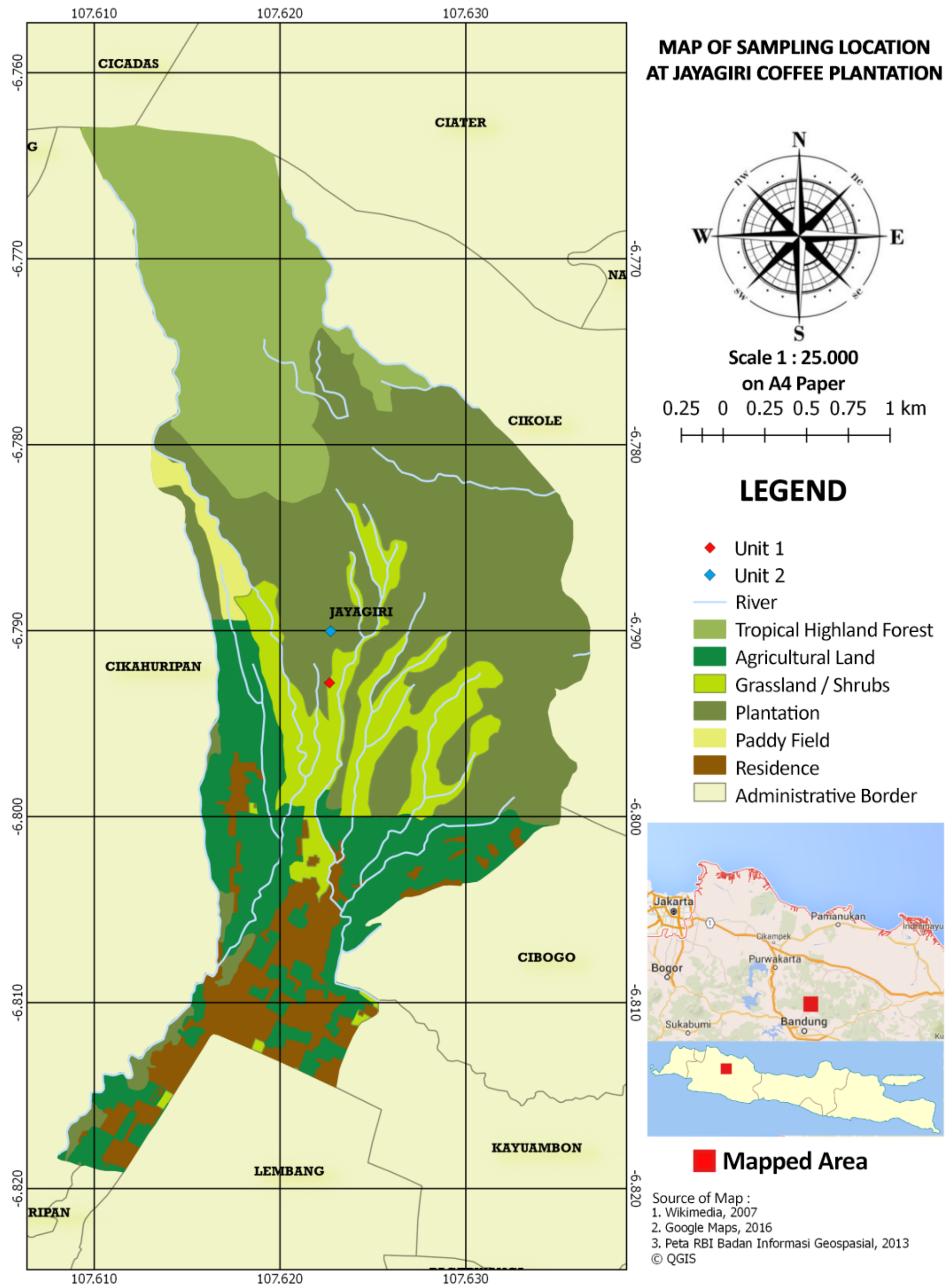

Figure 1. Map of research locations in Jayagiri Village, Lembang Sub-district, West Bandung District, West Java, Indonesia

Table 1. Types of understories around the coffee plants in Unit 1 observation site of Jayagiri Village, West Bandung District, West Java, Indonesia

Family	Species	Vernacular name
Apiaceae	*Centella asiatica* (L.) Urb.*	Pegagan
Araceae	*Colocasia esculenta* (L.) Schott*	Talas
Amaranthaceae	*Alternanthera sessilis* (L.) R.Br. Ex DC.*	Kremak
Compositae	*Ageratina riparia* (Regel) R.M.King & H.Rob.*	Teklan
	Ageratum conyzoides (L.) L.*	Babadotan
	Blumea balsamifera (L.) DC.*	Sembung
	Chromolaena odorata (L.) R.M.King & H.Rob.*	Tekelan
	Eupatorium inulifolium Kunth*	Kirinyuh
Hypoxidaceae	*Curculigo orchioides* Gaertn.*	Congkok
Leguminosae	*Aeschynomene indica* L.*	Katisem
	Euchresta horsfieldii (Lesch.) Benn.*	Prana jiwa
Malvaceae	*Urena lobata* L.*	Pulutan
Melastomataceae	*Clidemia hirta* (L.) D. Don.*	Harendong bulu
	Melastoma polyanthum Burm. F.*	Senggani
Oxalidaceae	*Oxalis corniculata* L.*	Calincing
Poaceae	*Axonopus compressus* (Sw.) P.Beauv.	Jukut pahit
	Eleusine indica (L.) Gaertn.	Jukut carulang
	Pennisetum polystachion (L.) Schult.	Rumput ekor kucing
	Themeda gigantea (Cav.) Hack. Ex Duthie	Pimping
Polygonaceae	*Persicaria chinensis* (L.) H. Gross*	Daun kesum
	Polygala paniculata L.*	Akar wangi
Rubiaceae	*Coffea arabica* L.	Kopi arabika
	Spermacoce alata Aubl.*	Gempur watu
Rosaceae	*Rubus rosifolius* Sm.*	Arbei
Solanaceae	*Solanum americanum* Mill.*	Leunca
Xanthorrhoeaceae	*Dianella ensifolia* (L.) DC.*	Dolar-dolaran
Zingiberaceae	*Zingiber officinale* Roscoe*	Jahe

Note: *) Have the potential to attract the coffee flower pollinator insects

The observation of the coffee flower pollinator insects was done by using an observation method (Klein et al. 2003). Observations were carried out for 25 minutes on each plot, during 09.00 am-02.00 pm, following the active period of insects searching for food. In unit 1 (coffee plantations with understory plants), the measurement of understory vegetation was done using a quadratic plot method. The pollinator insects, environmental parameters, and understory plants data were then processed and analyzed using ANOVA (*Analysis of Variance*) employing SPSS 16.0 application.

RESULTS AND DISCUSSION

A number of understory plant species were found under the coffee plantation of Unit 1 observation site. These understory plants (planted by the coffee plantation owners) included strawberries (*Rubus rosifolius*), ginger (*Zingiber officinale*), *leunca* (*Solanum americanum*), and yam (*Colocasia esculenta*). List of the understory plants found in unit 1 is presented in Table 1.

The majority of understory plant species in unit 1 was flowering plants with the potential to attract the coffee flower pollinator insects. Vegetation analysis results showed that the understory plants in Unit 1 had a moderate diversity level (Restu 2002) with Shannon-Wiener (H ') diversity index of 2.803. The dominant type was *haredong bulu* (*Clidemia hirta*) with the highest Importance Index (INP) of 33. 21%.

In addition to the understory plants, standing trees were also found inthe observation sites. These standing trees included pine (*Pinus merkusii*), *puspa* (*Schima wallichii*), jackfruit (*Artocarpus heterophyllus*), guava (*Psidium guajava*), *kembang merak* (*Caesalpinia pulcherrima*), and eucalyptus (*Eucalyptus camaldulensis*). Trees with the potential to attract the coffee flower pollinator insects were *puspa* (*S. wallichii*), jackfruit (*A. heterophyllus*), guava (*P. guajava*), *bunga merak* (*C. pulcherrima*), and eucalyptus (*E. camaldulensis*).

There was no understory plant around coffee plants in Unit 2 observation site since the understory plants in this unit were cleared by farmers for the reason that they were considered as weeds. The average altitude of the observation plots in unit 2 was 1484.4 m above sea level (asl). The general environmental conditions of unit 2 were the same as unit 1.

The standing trees found in unit 2 were pine (*P. merkusii*) and eucalyptus (*E. camaldulensis*). Flowering plants that could attract pollinator insects in unit 2 were eucalyptus. However, the eucalyptus plants were quite tall (40-45 m height), which made their flowers located far away from the coffee flowers. Consequently, the potential of eucalyptus as an attractant of the coffee flower pollinator insects is very low.

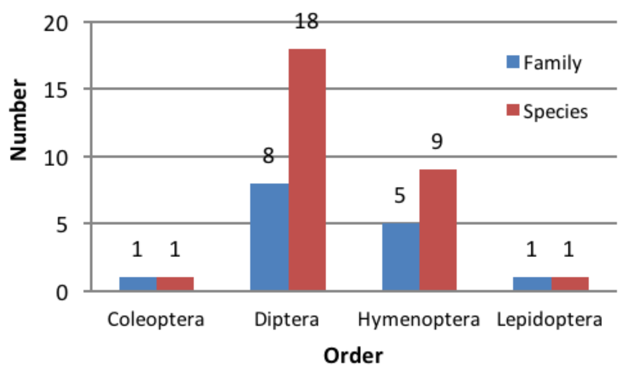

Figure 2. The number of family and species of each pollinator insect order

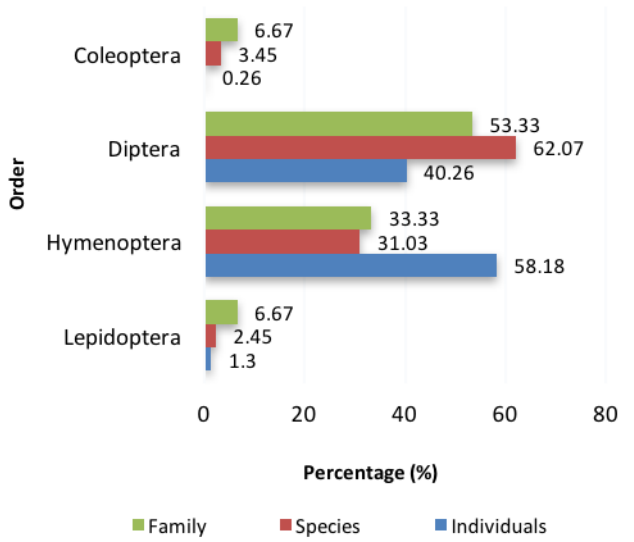

Figure 3. The percentage of family, species, and individuals of each pollinator insect order

The number of coffee flower pollinator insects found in all observation plots was 29 species from 15 families and four orders with a total of 385 individuals. Identification of the major insects was performed up to the family level, and some could be identified up to the genus and species levels. The number of observed pollinator insects by family and species is presented in Figure 2. Figure 2 shows that Diptera was the insect order with the largest number of family and species, while Lepidoptera and Coleoptera had the least amount of family and species.

The percentage of family, species, and individual of each order is presented in Figure 3. Figure 3 shows that Diptera had the largest percentage of family and species. However, the largest percentage of individuals was found in Hymenoptera. The Lepidoptera and Coleoptera had the same percentage of family and species, but the percentage of Lepidoptera individuals was slightly higher than that of Coleoptera.

Kearns (2002) mentioned that Diptera visited the flowers to get the nectar for its energy and pollen as its protein sources. Flowers produce species-specific substances that can be used by Diptera for mating and their microclimatic advantage.

According to Foottit and Adler (2009, Diptera has the largest proportion of pollinator insects in cold and humid habitats, such as rainforests, arctic, and high mountains. This is due to its well adaptive nature in humid and cold habitats, where bees are less active. This is in line with the present study results showing that at the research site located in the high, humid, and cold mountains, true pollinators like bees were less active. There were only two bee species recorded visiting the coffee flowers (6.9%) with a total of 8 individuals (2.08%) as compared toDipterawith 18 species (62.07%) with a total of 155 individuals (40.26%).

Insect order with the largest family and species after Diptera was Hymenoptera. Woodcock (2012) mentioned that bees are known to actively collect pollen and nectar for their larvae food supplies, and visit more flowers than other organisms that only feed for their own nutritional needs. Meanwhile, wasps look for prey or host (where the young wasps live) and eat the nectar of flowers for their personal needs.

There were fewer Hymenoptera family and species as compared to Diptera; however, the individual number of Hymenoptera was higher than Diptera with a total of 224 individuals (58.18%). This was caused by the higher number of visitations from Hymenoptera compared to Diptera. Hymenoptera had to provide food in its nest while Diptera did not have to do so, causing Diptera to linger in the flowers (Foottit and Adler 2009; Ssymank et al. 2009; AAC 2014).

Hymenoptera, especially bees, have been known as the most important pollinator insects for flowering plants. Although Diptera lacks the specific structures to aid the pollination process and does not have as many hairs as bees, it has also an important role contributing significantly to the success of plant productivity and is recorded as the second most important pollinator insect after bees (Foottitand Adler 2009; Ssymank et al. 2009; AAC 2014).

The pollinator insects of the coffee flowers with the least number of family and species observed here were Lepidoptera and Coleoptera with one species of one family each. Similar to Diptera, Lepidoptera provided no food for its young and had no hair like bees to trap pollen. Although the Lepidopteran adults consume nectar, they are considered as not to contribute significantly to pollination (AAC 2014).

According to Pohl (2009), butterflies tend to visit flowers of large size with yellow, orange, or purple colors rather than white color. The coffee flowers of small size and white color are not favored by butterflies, which was evidenced by the absence of butterflies visiting the coffee flowers during the observations.

Moths were the only Lepidoptera recorded visiting the coffee flowers in this study. According to Cunningham et al. (2004), moths that eat nectar because they attracted by the scent of the flowers they feed. The distinctive aroma of coffee flowers is probably attracting the moths to visit the coffee flowers in this study.

Five individuals of Lepidoptera were recorded visiting the coffee flowers while only one individual of Coleoptera was visiting the coffee flowers. According to AAC (2014), the Coleoptera tends to provide relatively limited contribution to pollination of flowering plants. In adjusting to its body shape and behavior, Coleoptera prefers bowl-shaped flowers with many stamens and pistils like palm oil plants. This is the reason why only one individual of Coleoptera was found in the observations site

Based on the Sorensen species similarity index, the species similarity between unit 1 and unit 2 was 0.766. Sorensen similarity index value approaching 1.0 indicated that the similarity of species in unit 1 and unit 2 was high or not much different. In this case, there were 18 species of insects found in both observation units from a total of 29 species of insects recorded during the observation.

According to Munyuli (2014), the abundance and diversity of pollinators is a significant contributor to the variation in coffee yields. This association shows that the increase in coffee yields is a direct contribution to the increase in the diversity and abundance of the coffee flower pollinator insects. Munyuli (2014) also found that the abundance and diversity of the coffee flower pollinator insects are important to maintain fruit formation and to improve the coffee yields. In the present study, the components of the visits such as the abundance and diversity of the coffee flower pollinator were proved to be related to the presence of understory plants.

Abundance of pollinators insects

The calculated abundance of pollinator insects in each of the observed plots is presented in Figure 4.

The results show that the coffee flower pollinator insects were more abundant in unit 1 than in unit 2. Unit 1 was the location with the understories surrounding the coffee plants. Within plot abundance of coffee flower pollinator insects also tended to be higher in unit 1 as compared to unit 2.

The abundance of coffee flower pollinator insects in unit 1 (location with understory plants) was significantly different from that of unit 2 (location without understory plants). Thus, the presence of understory plants in the vicinity of the coffee plants significantly affected the abundance of coffee flower pollinator insects. The present study result is in line with the research result of Munyuli (2014), where a positive relationship was observed between the amounts of vegetation in the area surrounding the coffee plants with the abundance of pollinator insects. The reason for this is that vegetation provides good nesting sites and food resources for pollinators.

Maintaining the habitat for pollinator insects can help increase the quantity and quality of coffee production. This is in line with Klein (2003) who urged coffee farmers to make improvements on their coffee plantation by providing better nesting sites for pollinators, especially solitary bees.

Ebeling et al. (2008) found that pollinator insect visits increase linearly with the increase of abundance and diversity of flowering plants. More abundant flowering plants will provide higher food availability, and more diverse flowering plants will provide better pollen and nectar resources for the pollinators. Thus, the presence of understory plants in unit 1 provided more abundant and more diverse flowering plants species than in unit 2 where the understory plants were cleared. Consequently, the pollinator insect in unit 1 was significantly more abundant than unit 2.

The diversity of the coffee flowers pollinator insect was calculated using the Shannon-Wiener diversity index as presented in Table 2.

Figure 3 shows that the average diversity index in unit 1 was higher than that in unit 2. The same situation applied to the within plot diversity index between the two observation units. Anova results showed no significant difference in varieties of coffee flowers pollinator insects between unit 1 (location with understory plants) and unit 2 (location without understory plants). Thus, the presence of understories in the vicinity of the coffee plants did not significantly affect the diversity of coffee flower pollinator insects. This is in line with the Sorensen type equality index (0.766) indicating that the level of similarity between unit 1 and unit 2 was high or not much different.

Community analysis of the pollinator insects

Data obtained from the two observation units were used to determine the structure and community of the coffee flower pollinator insects as presented in Figure 5.

The present study results show that *Tetramorium* sp. has the largest Relative Abundance (RA) in unit 1 and unit 2, respectively, 19.46% and 35.94%. *Tetramorium* sp. is included in the Hymenoptera order and the Formicidae family. Formicidae is commonly known as the social insect

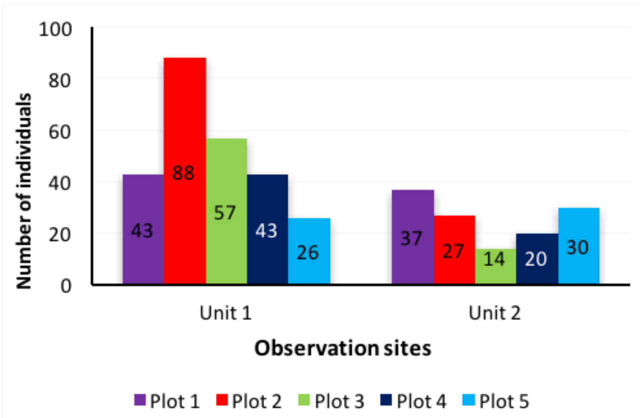

Figure 4. The abundance of pollinator insects of the coffee flowers

Table 2. Diversity Index of the coffee flowers pollinator insects

Site	Shannon-Wiener Diversity Index					
	The average	Plot				
		1	2	3	4	5
Unit 1	2.690	2.278	1.924	2.525	2.679	1.392
Unit 2	2.301	1.856	2.377	1.909	2.016	1.248

that has abundant individual colonies. Holldobler and Wilson (1990) claimed that Formicidae is the most dominant insect of the insect fauna. The more abundant *Tetramorium* sp. might have occurred because this insect is one of some species within Formicidae with a habit of returning to the same plant every day, even on the same flower branch.

Despite its higher abundance, Formicidae has a relatively small role in assisting flower pollination. Formicidae plays only a significant role as a pollinator in some flowering plants growing in hot and dry habitats where Formicidae is found abundant and active, nectar sources are easily accessible (helped by worker ants), and the habitats are short and woody. The volume size of the flower pollen is small to avoid the *grooming* stimulation in Formicidae due to the excess pollen and the small number of seeds per unit of flower so that less pollen is transferred (Holldobler and Wilson 1990).

There were only two species of bees found as the main pollinators in this observation, i.e. *Amegilla* sp. and *Xylocopa caerulea*. Both species were only found in unit 1 with RA value of 1.95% and 1.17%, respectively. The KR of *Amegilla* sp. was slightly higher than that of *X. caerulea* because *Amegilla* sp. is social bees living in colonies.

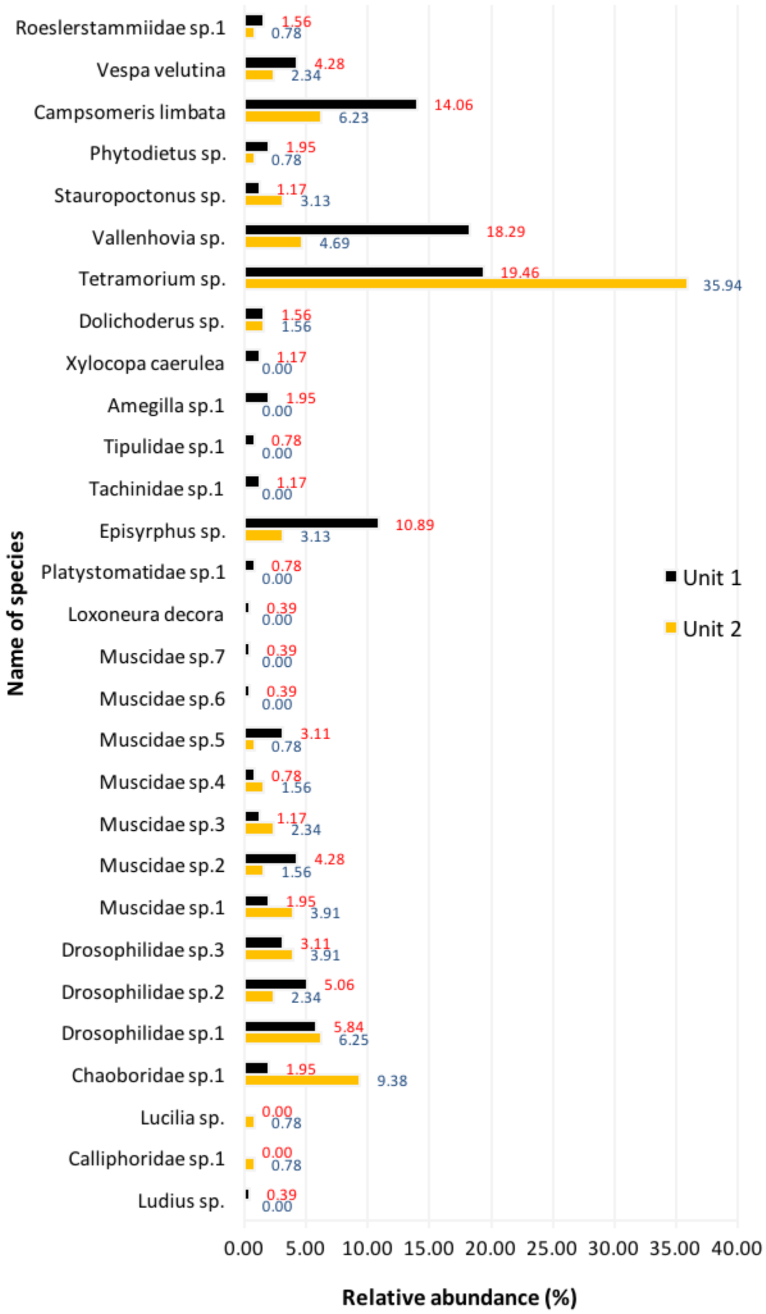

Figure 5. Relative abundance of the coffee flowers pollinator insects

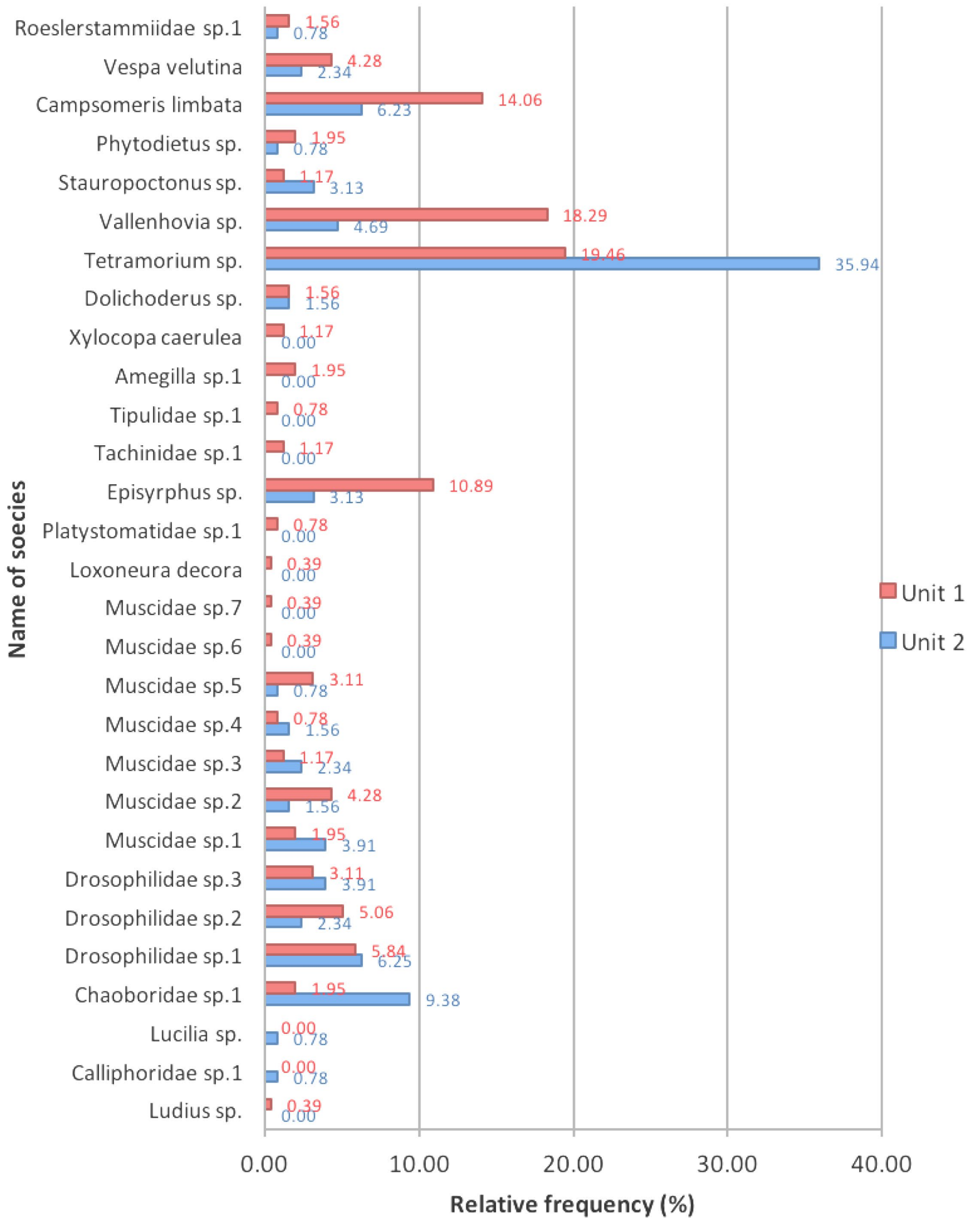

Figure 6. Relative Frequency of the coffee flower pollinator insects

Social bees will tell other bees in their hives about the food sources they encounter so that other bees can also pick up the same food sources. This is what distinguishes social bees and solitary bees. The solitary bees have no colonies so that the possibility of solitary bees within the same species visiting one flower is very low.

The RA value of *Tetramorium* sp. was much larger than that of *Amegilla* sp. and *X. caerulea*; however, this does not necessarily mean that *Tetramorium* sp. was more influential in pollinating coffee flowers. *Tetramorium* sp. is not hairy and has no pollen carrier structure (*pollen basket*) causing it is less efficient as a pollinator.

The RA value of*Amegilla* sp. was higher than that of *X. caerulea* but does not necessarily indicate that *Amegilla* sp. was more involved in coffee pollination than *X. caerulea* did. Klein et al. (2003) found that a single visit by a solitary bee can result in more coffee fruit formation than one visit by a social bee.

If seen from its appearance, there was no one type of insect pollinators present in all observation plots (10 plots, unit 1 and unit 2). However, there were several types of pollinator insects that were100% present in one observation unit (present in all five observation plots within a unit). The percentage of presence of species in the observation plot was determined by calculated Relative Frequency (RF) presented in Figure 6.

As seen in Figure 6, there were three species with Relative Frequency (RF) of 100% in unit 1 or present in every observation plot, i.e., *Drosophilidae* sp.2, *Muscidae* sp.2, and *Tetramorium* sp., and two species with FR of 100% in unit 2, i.e., *Drosophilidae* sp.*1* and *Campsomeri slimbata*. Species with 100% RF indicated their wide distribution within the observation unit. The Drosophilidae family had a 100% presence in both unit 1 and 2; *Drosophilidae* sp.2 species was found in unit 1, and *Drosophilidae* sp.1 species was found in unit 2. The high presence of Drosophilidae was due to its cosmopolitan nature, which enables it to be found on a wide range of habitat types.

Species not found (0% RF) in unit 1 were *Lucilia* sp. and *Calliphoridae* sp.1 from the Calliphoridae family while those not found in unit 2 (0% RF) included *X. caerulea*, *Amegilla* sp., *Tipulidae* sp.1, *Tachinidae* sp.*1*, *Platystomtidae* sp.1, *Loxoneura decora*, *Muscidae* sp.7, *Muscidae* sp.6, and *Ludius* sp.

The absence of a species in a region is influenced by many factors such as biotic and abiotic factors. Among biotic factors influencing the existence of a species is the presence of a predator or a certain species as the food source. Abiotic factors influencing the existence of a species is the environmental conditions such as light intensity, wind speed, humidity, and air temperature.

The diversity type in each unit in this study was calculated using the Simpson index and Shannon-Wiener diversity index as presented in Figure 7.

Based on the above diagram, it appears that Simpson's index was in reverse to the Shannon-Wiener index. According to Fitriana (2005), the Simpson index can show the diversity as well as the balance of the number of individuals. The higher the Simpsons Index value, the more dominant a particular species in a community is, causing a low diversity. This statement agrees well with the results of the present study. The Shannon-Wiener Index value in unit 1 (2.690) was higher than that in unit 2 (2.301) while the Simpsons Index value was lower in unit 1 (0.101) than that in unit 2 (0.172).

The results show that the diversity in unit 1 was higher than unit 2 because there was a dominant type occurred in unit 2. Although there was a more dominant type existed in unit 2, the close-to-zero Simpsons Index in unit 2 indicated that the dominance found in unit 2 was still at a low level (Fitriana 2005). The low-level dominance in unit 2 is proven by the value of the Shanon-Wiener Index which was not much different from unit 1 and equally belonged to medium diversity level (Fitriana 2005).

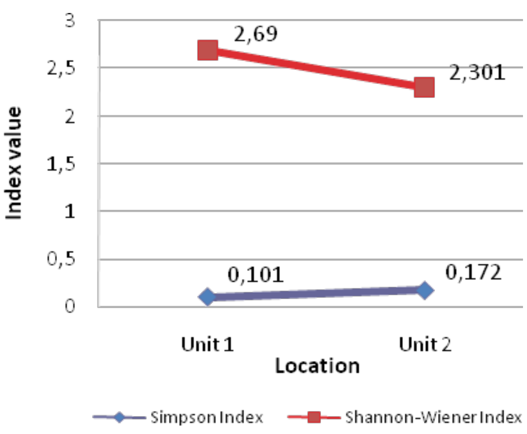

Figure 7. Simpsons and Shannon-Wiener Index

In conclusion, the abundance of the coffee flower pollinator insects in coffee plantations with understory plants was significantly higher ($P < 0.05$) than in areas where understory plants were cleared. Similarly, the diversity of the coffee flower pollinator insects in coffee plantations with understory plants was also higher than that of coffee plantations without understory plants.

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