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Effect of farmer's behavior in cocoa management on insect diversity in Salayo Cocoa Plantation, West Sumatra, Indonesia

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Abstract. *Rosalia S, Yonariza, Syahrawati M. 2022. Effect of farmer's behavior in cocoa management on insect diversity in Salayo Cocoa Plantation, West Sumatra, Indonesia. Biodiversitas 23: 5064-5073.* The behavior of farmers in cocoa cultivation will affect the cocoa (*Theobroma cacao*) plantation environment and all living things in it, including insects. Disruption of insect diversity will also affect the ecosystem services insects provide, especially those related to improving the quality and quantity of agricultural products, especially cocoa. This study aimed to determine and analyze the diversity of insects in cocoa plantations and the role of insects in the ecosystem. This research was carried out at the Salayo Cocoa Plantation, a small-scale farmers' cocoa plantation in Nagari Salayo, Kubung District, Solok Regency, and the Bioecology Laboratory, Plant Protection Department, Faculty of Agriculture, Andalas University, from July to October 2021. Insect collection was carried out using pitfall traps, yellow sticky traps, light traps, and spraying with insecticides. Insect sampling was carried out three times. The results showed that in cocoa plantations in Nagari Salayo, Kubung District, Solok Regency, insects from 12 orders, 31 families, and 58 species with a total number of 750 individuals were found, and insect diversity was in the range of 1-3322. Based on their role, the collected insects can be divided into pests, decomposers, pollinators, predators, parasitoids, and neutral insects. The richness and abundance of herbivores were lower than carnivores (predators and parasitoids). The predators with the highest number were Formicidae (Hymenoptera). Good farmer behavior in managing the cocoa plantation can maintain insect diversity and the sustainability of ecosystem services provided by insects.

Keywords: Abundance, diversity, ecosystem services, Formicidae, *Theobroma cacao*

INTRODUCTION

Cocoa is one of the primary plantation commodities that play an important role in Indonesia, and it is managed mainly by the small-scale farmer (97.42%), the private sector (1.92%), and the government (1.41%) (Ministry of Agriculture of Indonesia 2016). Recently, Praseptiangga et al. (2020) reported that approximately 95% of cocoa (*Theobroma cacao*) plantations in Indonesia belong to small-scale farmers, and cocoa production is the primary income source for over 1,400,000 farmers and their families. Statistics Indonesia (2021) showed a downward trend in cocoa production in Indonesia, starting from 740,513 tons in 2012 to 720,660 tons in 2020. The main problem faced in small-scale farmers' plantations is low productivity due to a lack of knowledge regarding pests and diseases and how to treat them. Cocoa pod borer (*Conopomorpha cramerella*) causes significant yield loss of up to 80-90% (Saleh et al. 2020a), and cocoa black pod rot (*Phytophthora palmivora*) causes significant pod losses up of to 30% and kills up to 10% of the trees annually (Guerrero et al. 2012).

Pesticides, pruning, and land sanitation are the three main maintenance techniques to control pests and diseases on cocoa plants (Fausayana et al. 2018). In fact, the choice and behavior of farmers in controlling pests and diseases affect not only pests and diseases directly but also the environment, including insect diversity. Insects that exist in cocoa plantations are very diverse, but not all of them are pests. Within the ecosystem, insect functions as herbivore, carnivore, detritivore, and pollinator (Pora et al. 2016). Insects play an important role in maintaining the function and stability of ecosystems (Yang and Chen 2021), optimizing ecosystem services (Chowdury et al. 2017), and also increases the quality and quantity of crop yield (Katumo et al. 2022). Insect abundance and distribution are regulated by several biotic and abiotic factors and their interactions (Soultani et al. 2012). According to Zakariyya et al. (2016), biomass derived from pruning cacao plantations can be a place for cocoa insect pollinators to live.

About 79.8% of farmers control their existence using pesticides (Swisscontact 2017). The use of agrochemicals leads to a reduction in soil macro-fauna diversity and abundance in cocoa plantations (Tsufac et al. 2021). The diversity and abundance of predators and parasitoids in the cocoa plantation without using insecticides (11 families) was higher than using insecticides (eight families) (Syarief et al. 2017). The diversity of pests in the organic plantation was relatively lower, but the diversity of natural enemies, such as predators, was higher (Ransford et al. 2021).

Meanwhile, Adjaloo and Oduro (2013) found seven orders and 36 species of insects on a cacao plantation, about 40% of the insect species were crawling insects belonging to Coleoptera and Hymenoptera.

West Sumatra is among Indonesia's top seven highest cocoa-producing provinces. However, its production trend continues to decline from 2018 to 2020, with a growth of-28.80%. Pests and disease are the most significant contributors to the decrease in cocoa production. The total area of pest attacks in the fourth quarter of 2020 was 16,580 ha, with a potential yield loss of IDR 1,064,451,000 (Department of Estate Crop Food Crop and Horticulture of West Sumatra Province 2021). There is a commonly-held view that pest control is best achieved within a framework of Integrated Pest Management, but it has not worked well. Salayo Cacao Plantation (SCP) is a small-scale farmer plantation in Solok Regency, West Sumatra, Indonesia. One of the SCP farmers represented Solok Regency to participate in the competition as an outstanding farmer and became the first winner of the high-production cocoa plantation competition in 2018, which was held by the Directorate General of Plantations, Ministry of Agriculture of the Republic of Indonesia. Then, Nagari Salayo was selected as the host for the Indonesian Cocoa Day celebration in 2019. This research aimed to know the insect diversity around Salayo Cocoa Plantation and the role of insects in the ecosystem.

MATERIALS AND METHODS

Study area

This study was conducted at a small-scale farmer's Cocoa Plantation in Nagari Salayo, Kubung District, Solok, West Sumatra, Indonesia (Figure 1). Nagari Salayo occupies an area of 21.44 km^2 or about 11.17% of the total area of Kubung District, and consists of four villages; Luhak Nan Tigo, Sawah Sudut, Galanggang Tangah, and Batu Palano. Geographically, Nagari Salayo is located at an altitude of 390-526 m above sea level, with 2141 mm of rainfall per year and an average of 145.1 days of rain per year. Nagari Salayo has boundaries, to the north, it is bordered by Solok, to the south, by Nagari Gantung Ciri, to the west, by Nagari Koto Hilalang and Bukit Barisan, to the east, by Nagari Koto Baru (Carlo and Rita 2019).

Procedure

Insect collection

There were only 3 farmer groups that cultivated cocoa plants in Salayo. Insect collection was carried out at Salayo Cocoa Plantation (SCP) belonging to the Bungo Tanjung Sepakat farmer group (38.13 ha), Saiyo farmer group (24.40 ha), and Manunggang Sakato farmer group (10.6 ha). There were 10 observation plots measuring 2x2 m were made in three locations. Collecting insects was done using a pitfall trap, yellow sticky trap, canopy spraying, and light trap (Figure 2). Sample collection was carried out once every two weeks and repeated 3 times per location.

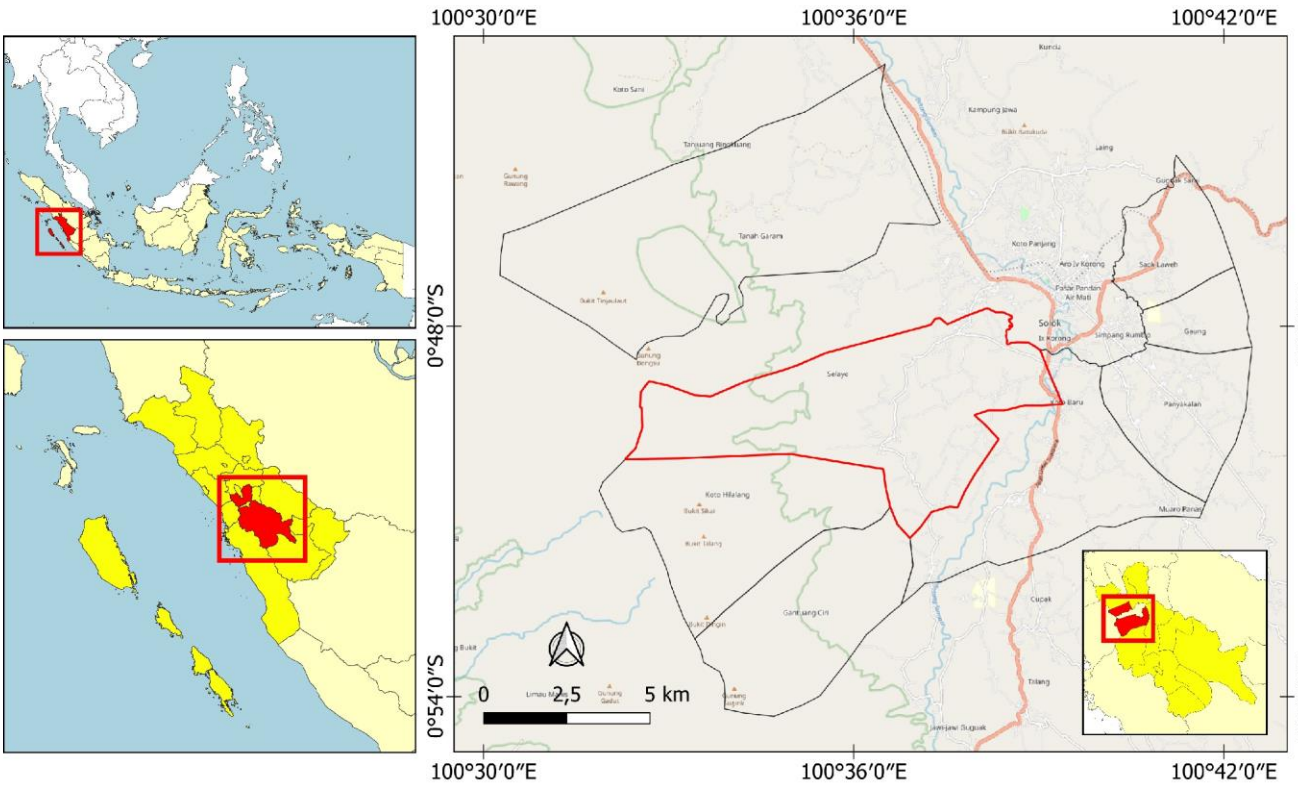

Figure 1. Map of Salayo Cocoa Plantation located in Nagari Selayo, Kubung District, Solok Regency, West Sumatra, Indonesia

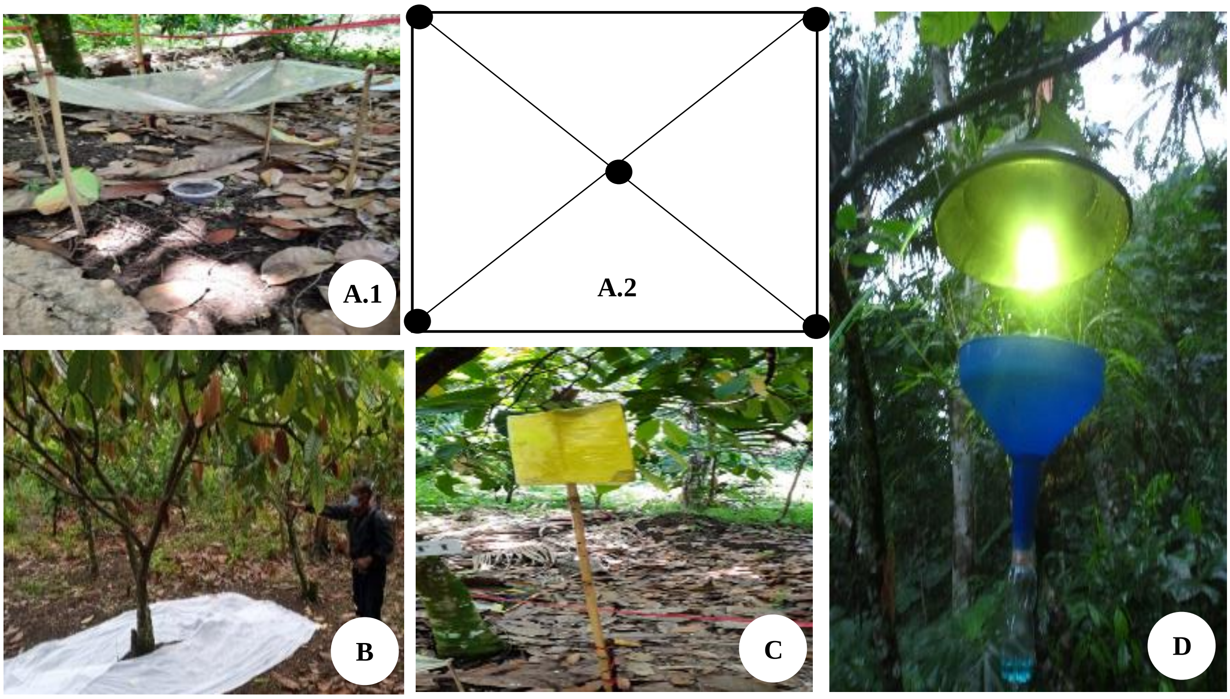

Figure 2. Insect collection by: A.1. Pitfall trap; A.2. Pitfall placed diagonally; B. Yellow sticky trap; C. Canopy spraying; D. Light trap modified

Pitfall traps (Pt) were made from mineral plastic cups filled with 1/3 cup of water and detergent (10%). Pt was inserted into the soil, which was laid flat to the soil surface. There were 5 Pts placed diagonally at each location during 6am-6pm. The yellow sticky traps (Yst) were made of yellow paper measuring 30x30 cm, which were placed on the land using bamboo as high as ±150 cm. One Yst was placed in one location during 6am-6pm. Canopy spraying was carried out by spraying synthetic pyrethroid insecticides on the canopy of one cocoa plant in the plot area. A piece of white cloth was spread on the ground to capture fallen insects. The light traps (Lt) used a modified electric lamp and were placed as high as ±150 cm, the holding bucket was filled with water and detergent (10%). One Lt was placed in each observation plot during 6pm-6am.

The collected insects were put in a bottle containing alcohol (70%), then identified at the Insect Bioecology Laboratory, Plant Protection Department, Faculty of Agriculture, Andalas University, referred to Triplehorn and Johnson (2005) and bugguide.net. Identification was done until species. The parameters observed included the insect species, abundance, diversity, evenness and roles in ecosystem services.

Data analysis

Data analysis was carried out by calculating the richness, abundance of species, diversity of insects, evenness index and similarity index. The species richness index was calculated using the Margalef formula (Mokam et al. 2014):

$$DMg = \frac{S-1}{\ln N}$$

The index of species richness and species abundance was calculated using Microsoft Excel (MS. Excel). Species abundance was measured using the following formula (Juniarti and Rusniarsyah 2022):

$$Ki = \frac{ni}{A}$$

Insect diversity was calculated using the Shannon-Wiener (H) index (Wakhid et al. 2020). The Diversity Index was used to compare the high and low performance of the insect species, with the formula:

$$H' = -\Sigma \text{ Pi ln Pi}$$

The evenness index was calculated with formula E=H'/lnS. Equitability assumes a value between 0 and 1, with 1 being complete evenness (E) (Puspasari et al. 2021). The similarity index was calculated with formula CJ = J/(a+b-J). The value of the Jaccard similarity index (Cj) is close to 1, indicating a high level of similarity between habitats. If the similarity index value Jaccard (Cj) is close to 0, indicating the level of similarity between habitats is low (Rohyani 2021).

Farmer's behavior

Farmers in Manunggang Sakato have the best behavior in applying pesticides, conducting land sanitation and pruning (Table 1). Although farmers in the three locations applied several pesticides (insecticides, fungicides, and herbicides) to their cocoa plantations, but farmers in Manunggang Sakato applied the least number of these pesticides (Table 2).

Table 1. Farmer behavior in cocoa management in three locations in Salayo Cocoa Plantation

Behavior	Salayo Cocoa Plantation		
	Bungo Tanjung Sepakat	**Saiyo**	**Manunggang Sakato**
Applying pesticide wisely	+	+	v
Doing land sanitation	+	+	v
Pruning	+	v	v

Notes: -= less; + = enough; v = good

Table 2. Pesticides selected and applied by farmers in three locations in Salayo Cocoa Plantation

Pesticide	Ingredient	Salayo Cocoa Plantation		
		Bungo Tanjung Sepakat	**Saiyo**	**Manunggang Sakato**
Insecticide	Imidacloprid	v	-	-
	BPMC	-	-	v
	Carbosulfan	-	v	-
	Lambda Sihalothrin	v	v	v
Fungicide	Mankozeb	v	v	v
	Diphenoconazole	v	-	-
	Azoxystrobin	-	v	-
Herbicide	Glyphosate	v	v	-

Table 2. Guidelines for determining the category of knowledge, attitudes, practice, and behavior of farmers in applying pesticides, sanitation, and pruning cocoa plants

Knowledge		
Scale of score	Score after converted	Category
3.4-5.0	68-100	good
1.7-3.3	34-67	enough
0-1.6	0-33	less
Attitude		
Scale of score	Score after converted	Category
18.4-25.0	73.4-100	good
11.7-18.3	46.7-73.3	enough
5.0-11.6	20.0-46.6	less
Practise		
Scale of score	Score after converted	Category
18.4-25.0	73.4-100	good
11.7-18.3	46.7-73.3	enough
5.0-11.6	20.0-46.6	less
	Behavior	
Number scale score	Score after converted	Category
40.2-55.0	73.0-100	good
25.1-40.1	45.6-72.9	enough
10.0-25.0	18.2-45.5	less

A questionnaire was prepared to collect data about farmer behavior from 75 farmers in Cocoa Salayo Plantation. The questionnaire was prepared based on farmers' knowledge, attitudes, and actions related to pesticide application, sanitation, and pruning. The questionnaires were prepared based on farmers' knowledge, attitudes, and practices; regarding pesticide application, sanitation, and pruning. Each section was delivered in five statements, made into three categories (good, enough, and less). The knowledge responses were scored 0-5 (wrong to correct) on a scale of 1.6. The attitudes and the practices were scored 5-25 on a scale of 6.6. Farmers' behavior in applying pesticides, sanitation, and pruning were grouped by combining the scores of knowledge, attitudes, and practices were scored 10-55 on a scale of 15. The obtained value was then converted to a percentage (Table 2).

RESULTS AND DISCUSSION

Abundance and species richness of insect

Insects were collected in Salayo Cocoa Plantation consisted of 11 orders, 31 families, 58 species and 750 individuals. The highest abundance of insect was found in Manunggang Sakato, the highest abundance species was *Anoplolepis* sp., the lowest abundance of insect was found in Bungo Tanjung Sepakat, the highest abundance species was *Dolichoderus thoracicus*, and the abundance species in Saiyo was *Iridomyrmex* sp. All of them belong to Formicidae (Hymenoptera). Data on the insect abundance in the three locations can be seen in Table 3.

The results of this study were different from another study. Srinivasnaik et al. (2016) found 23 herbivores and 13 species as natural enemies in South India. Among herbivores, 14 species are classified as sucking pests, two as borers, and seven species are classified as defoliators. Furthermore, seven species are classified as predators among the natural enemies, and six are classified as parasitoids. Indriati et al. (2020) found nine insect orders in cocoa plantations in West Java, which is dominated by Braconidae (Hymenoptera), classified as a parasitoid. Ransford et al. (2021) found 12 orders, 63 families, and 138 species from the organic and inorganic cocoa plantations. The diversity of natural enemies, such as predators, was higher in an organic cocoa plantation, but herbivore diversity was relatively lower. Meanwhile, Syafiqah and Askarali (2018) found four orders and ten families of insects in the cocoa field at ladang UiTM Jasin, led by Hymenoptera, followed by Coleoptera, Orthoptera, and Hemiptera. Yuswana et al. (2018) found six families of Coleoptera, the highest density was Scolytidae family (34.20%), classified as herbivores. The abundance of those species is supported by the behavior of farmers in cultivation, the pesticides applied, and the preferences of these insects. Intensive use of synthetic insecticides caused lower diversity and abundance of predators and parasitoids (Syarief et al. 2017). Insect abundance and diversity were generally higher in organic cocoa farms compared to conventional cocoa farms (Ransford et al. 2021).

Table 3. Abundance of insect species in three locations in Salayo Cocoa Plantation, West Sumatra, Indonesia

Order	Family	Species	Bungo Tanjung Sepakat		Saiyo		Manunggang Sakato	
			Ind.	Abund.	Ind.	Abund.	Ind.	Abund.
Blattodea	Ectobiidae	*Blattella* sp.	0	-	5	0.21	0	-
Coleoptera	Carabidae	*Cylindera* sp.	0	-	2	0.08	3	0.25
		Cylindera viduata	0	-	1	0.04	6	0.50
	Coccinellidae	*Coelophora* sp	0	-	0	-	8	0.67
	Curculionidae	*Otiorhynchus* sp.	2	0.50	19	0.79	3	0.25
		Anthonomus sp.	0	-	24	1.00	5	0.42
	Scarabaeidae	*Apogonia* sp.	0	-	0	-	4	0.33
		Anomala orientalis	0	-	1	0.04	0	-
		Ataenius spretulus	5	1.25	30	1.25	20	1.67
		Ataenius sp.	0	-	0	-	4	0.33
		Diapterna sp.	3	0.75	0	-	0	-
		Onthophagus binodis	0	-	0	-	1	0.08
		Oryctes rhinoceros	0	-	1	0.04	2	0.17
		Phanaeus vindex	0	-	27	1.13	4	0.33
		Phyllophaga sp.1	0	-	32	1.33	2	0.17
		Phyllophaga sp.2	0	-	11	0.46	0	-
	Staphylinidae	*Paederus fuscipes*	2	0.50	0	-	3	0.25
Dermaptera	Forficulidae	*Forficula auricularia*	2	0.50	13	0.54	2	0.17
Diptera	Culicidae	*Aedes* sp.	0	-	38	1.58	13	1.08
		Aedes sollicitans	1	0.25	0	-	3	0.25
	Drosophilidae	*Drosophila* sp.	2	0.50	9	0.38	0	-
	Muscidae	*Neomyia cornicina*	0	-	2	0.08	1	0.08
	Stratiomyidae	*Hermetia illucens*	0	-	2	0.08	0	-
	Tachinidae	*Sturmiopsis* sp.	0	-	28	1.17	1	0.08
	Tephritidae	*Bactrocera* sp.	0	-	30	1.25	0	-
		Bactrocera carambolae	1	0.25	0	-	0	-
		Trupanea sp.	0	-	0	-	17	1.42
Hemiptera	Alydidae	*Leptocorisa oratorius*	0	-	3	0.13	0	-
	Aphididae	*Toxoptera* sp.	0	-	0	-	1	0.08
	Cicadidae	*Tibicen* sp.	0	-	1	0.04	4	0.33
	Flatidae	*Sanurus indecora*	0	-	0	-	2	0.17
	Miridae	*Helopeltis* sp.	0	-	2	0.08	0	-
	Reduviidae	*Melanolestes* sp.	0	-	1	0.04	0	-
		Sycanus sp.	0	-	2	0.08	0	-
		Zelus longipes	0	-	1	0.04	0	-
Hymenoptera	Formicidae	*Anoplolepis* sp.	2	0.50	30	1.25	38	3.17
		Anoplolepis gracilipes	0	-	20	0.83	9	0.75
		Austroponera sp.	3	0.75	0	-	1	0.08
		Dolichoderus sp.	0	-	13	0.54	14	1.17
		Dolichoderus thoracicus	29	7.25	3	0.13	13	1.08
		Iridomyrmex sp.	2	0.50	61	2.54	21	1.75
		Myrmecocystus sp	0	-	0	-	2	0.17
	Ichneumonidae	*Goryphus mesoxanthus*	2	0.50	0	-	0	0.00
	Vespidae	*Vespa affinis*	1	0.25	1	0.04	2	0.17
Isoptera	Rhinotermitidae	*Coptotermes curvignathus*	1	0.25	2	0.08	11	0.92
Lepidoptera	Gracillariidae	*Conopomorpha cramerella*	1	0.25	7	0.29	4	0.33
	Pyralidae	*Ephestia cautella*	1	0.25	0	-	0	-
Mantodea	Mantidae	*Mantodea* sp.	0	-	2	0.08	1	0.08
Orthoptera	Acrididae	*Xenocatantops* sp.	0	-	1	0.04	0	-
	Blattidae	*Periplaneta americana*	0	-	0	-	3	0.25
	Gryllidae	*Allonemobius fasciatus*	1	0.25	12	0.50	0	-
		Gryllus assimilis	1	0.25	0	-	10	0.83
		Acheta domesticus	0	-	0	-	1	0.08
	Tettigoniidae	*Scudderia* sp.	0	-	1	0.04	0	-
		Neoconocephalus ensiger	0	-	2	0.08	1	0.08
		Conocephalus sp.	0	-	1	0.04	0	-
		Odontoxiphidium sp.	0	-	2	0.08	4	0.33
Thysanoptera	Thripidae	*Thrips parpisvinus*	0	-	0	-	1	0.08
11	31	58	62		443		245	

Note: Ind.: individual; Abund.: Abundance

In the agricultural area, ants are insects with high abundance and community and have many roles, including as predators, decomposers, herbivores, and bioindicators for the health of agricultural ecosystems (Sanda and Sunusi 2014; Ikhsan et al. 2020). Ants can positively influence plants and humans (Abdullah 2020; Andersen 2021). Insect abundance and distribution are regulated by several biotic and abiotic factors and their interactions, which are supported by appropriate environmental conditions and the sufficiency of their food source needs (Soultani et al. 2012; Haerul et al. 2019). Besides that, the diversity and abundance of ant species are influenced by ecological factors such as nesting sites, microhabitats, food availability, and food diversity (Carval et al. 2016). Food availability is an important factor influencing the lives of ant colonies; dominant ant species can monopolize space and food resources (Vele and Modlinger 2016; Garcia et al. 2022).

In terms of competition for food sources, we found other ant species that have the potential to be competitors for food sources, such as *Anoplolepis* sp. The abundance of ant *Anoplolepis* sp. assumed that influenced by the presence of cocoa leaf litter at the insect sample collection area. Johari et al. (2021) stated that *Anoplolepis* sp. is one of the most common ant species found in an oil palm plantation because litter is still found in the location that allows *Anoplolepis* sp. to gather and make nests. *Anoplopepis* sp. is most commonly found in residential areas (Schultz and McGlynn 2000).

The location of cocoa plantations in Manunggang Sakato, which is close to residential areas, is also assumed to be one of the factors supporting the abundance of *Anoplolepis* sp. Then, *Iridomyrmex* sp. was found in an open area without cover crops like in Saiyo. The low-density canopy areas allowed sunshine penetration to the ground and the leaf litter, causing low moisture humidity in the soil and dry leaf litter, resulting in a suitable habitat for *Iridomyrmex* sp. (Wanna et al. 2022). Shahabuddin (2010) stated that microclimate conditions determine the occurrence of habitat selection by insects. The microclimate follows changes in the structure of the vegetation; an open canopy of plants or a closed canopy in a habitat can affect preferences and habitat selection by insects. Middleton et al. (2018) reported that *I. purpureus* prefer building nests in open sunny areas. Meanwhile, *D. thoracicus* prefer optimal shade levels and wide canopy cover (Bakar 2014). This condition was found in Bungo Tanjung Sepakat. *D. thoracicus* is one of the effective species for the biological control of cocoa pod borer *Helopeltis antonii* (Syarief et al. 2017; Saleh et al. 2020b). *Sycanus* sp. is identified as a predator of *Helopeltis* sp. (Nitin et al. 2017), and it was also found in Saiyo.

The species richness of the three locations ranged from 4.36 to 6.91, included in the high criteria, with moderate productivity and environmental pressure, and the ecosystem was relatively stable. The presence of insects can be used as an indicator of the balance of the ecosystem. The highest species richness index was found in the Manunggang Sakato (6.91), and the lowest was in Bungo Tanjung Sepakat (4.36) (Figure 3). Evenness index value close to 1 indicates that no species dominated in the three locations. The evenness index of the three locations ranged from 0.71 to 0.86 (Figure 4). The presence of insects is influenced by the environment and food availability. Similarity index between the three locations ranged from 0.23-0.44. The level of similarity between the three locations is said to be low because it has a value close to 0 (Table 4). Insect diversity is an important part of ecosystems' biodiversity and becomes a critical link in the food chain. It plays an important role in maintaining the function and stability of ecosystems (Yang and Chen 2021).

Role of insects

Insects collected in Salayo Cocoa Plantation was based on their role in the ecosystem can be divided into herbivores, carnivores, decomposers, pollinators and others. The number of herbivores occupied the highest position with 7 orders, 15 families, 23 species and 173 individuals, while the carnivore was dominated by predators with 6 orders, 9 families, 17 species and 323 Individuals (Table 5). The Insects in Salayo Cocoa Plantation were dominated by carnivores (47%), consisting of predators and parasitoids, and then followed by herbivores (23%) (Figure 5).

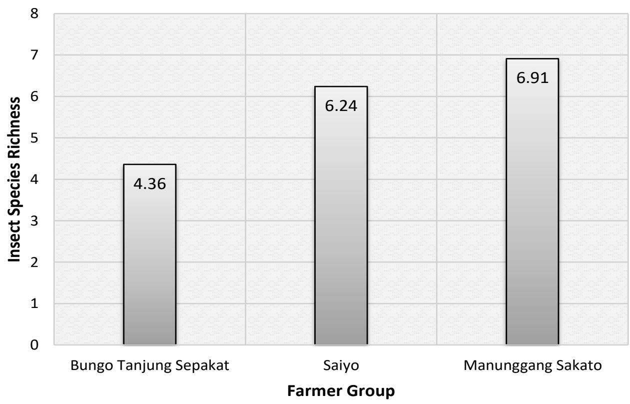

Figure 3. The species richness index of insect in three locations at Salayo Cocoa Plantation

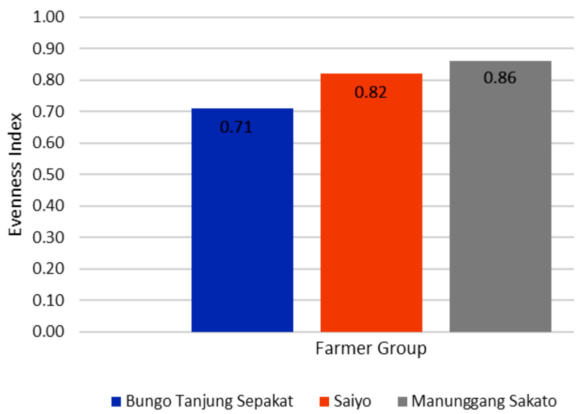

Figure 4. The evennes index of insect in three locations at Salayo Cocoa Plantation

Table 4. Insect similarity index between three locations in Salayo cocoa plantation

Farmer group	Similarity Index
Bungo Tanjung Sepakat vs Saiyo	0.23
Bungo Tanjung Sepakat vs Manunggang Sakato	0.29
Saiyo vs Manunggang Sakato	0.44

Table 5. The role of insects at three locations in Salayo Cocoa Plantation

Role	Order	Family	Species	Individual
Herbivores				
Curculionidae (Coleoptera)	7	15	2	53
Scarabaeidae (Coleoptera)			2	7
Tephritidae (Diptera)			3	48
Alydidae (Hemiptera)			1	3
Aphididae (Hemiptera)			1	1
Cicadidae (Hemiptera)			1	5
Flatidae (Hemiptera)			1	2
Miridae (Hemiptera)			1	2
Rhinotermitidae (Isoptera)			1	14
Gracillariidae (Lepidoptera)			1	12
Pyralidae (Lepidoptera)			1	1
Acrididae (Orthoptera)			1	1
Gryllidae (Orthoptera)			2	12
Tettigoniidae (Orthoptera)			4	11
Thripidae (Thysanoptera)			1	1
Carnivores (Predator)				
Carabidae (Coleoptera)	6	9	2	12
Coccinellidae (Coleoptera)			1	8
Staphylinidae (Coleoptera)			1	5
Forficulidae (Dermaptera)			1	17
Reduviidae (Hemiptera)			3	4
Vespidae (Hymenoptera)			1	4
Mantidae (Mantodea)			1	3
Gryllidae (Orthoptera)			1	13
Formicidae (Hymenoptera)			6	257
Carnivores (Parasitoid)				
Tachinidae (Diptera)	2	2	1	29
Ichneumonidae (Hymenoptera)			1	2
Decomposers				
Scarabaeidae (Coleoptera)	6	6	8	140
Ectobiidae (Blattodea)			1	5
Muscidae (Diptera)			1	3
Stratiomyidae (Diptera)			1	2
Formicidae (Hymenoptera)			1	4
Blattidae (Orthoptera)			1	3
Polinator				
Drosophilidae (Diptera)	1	1	1	11
Others				
Culicidae (Diptera)	1	1	3	55

In cocoa plantations (Bungo Tanjung Sepakat, Saiyo and Manunggang Sakato), several insect species were identified as the main pests on cocoa plants, such as the cocoa pod borer (*Conopomorpha cramerella*) and the cocoa pod-sucking insect (*Helopeltis* sp.). Other insect pests that were not the main pests on cocoa plants were also identified, namely *Apogonia* sp. and *Ephestia cautella*, which was a type of warehouse pest that is often found in cocoa bean storage areas in Indonesia (Samsudin et al. 2016).

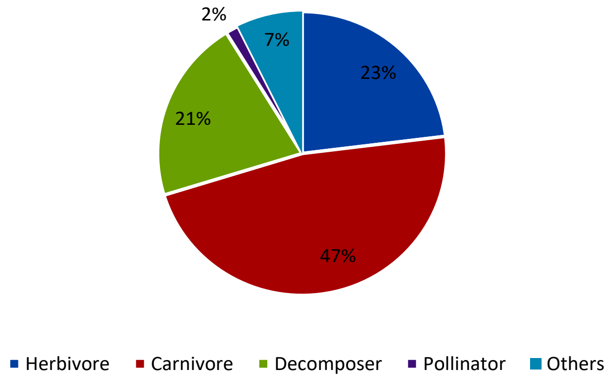

Figure 5. The role of insect percentage in Salayo Cocoa Plantation

Decomposers were identified coming from the cocoa plantations in the three locations, the highest number of decomposers was Scarabaeidae (Table 4). The Scarab beetles or dung beetle consist of over 27,800 species throughout the world. Scarab beetles are considered the most significant insect assemblies in the tropical zones because of their vital role in nutrient recycling, helminth control, and seed dispersion as they use the dung of herbivorous and omnivorous mammals as a food reserve (Shah and Shah 2022). Dung beetle activity in the soil is essential for soil health and plays an important role in any ecosystem. Agricultural systems will benefit from the ecosystem services a diverse dung beetle assemblage provides by supporting soil health and decreasing the need for chemical fertilizer (Jankielsohn 2021).

In Bungo Tanjung Sepakat and Saiyo, the two pollinators collected were Drosophilidae (Diptera) and Formicidae (Hymenoptera), while the pollinator collected in Manunggang Sakato was Formicidae (Table 4). Several studies have reported that Hymenoptera is an order of insect pollinators mostly found and dominant in all habitat types (Siregar et al. 2016; Bashir et al. 2019; Koneri et al. 2021). The presence of pollinating insects is strongly influenced by the availability of flowering plants in their habitat. The reduction in flowering plants led to a decrease in pollinating insect species (Koneri et al. 2021). According to Bailey et al. (2014), insect pollinators are thermophilous, they prefer warm open areas to forage and also travel further out into the field to forage in open areas as well. Sheffield et al. (2013) reported that habitats with low human disturbance characteristics have a higher abundance of insect pollinator species compared to intensively managed agricultural lands. Species pollinating cocoa flowers like *Drosophila* sp., *Dolichoderus* sp. (Tarmadja 2015; Claus et al. 2018). Adjaloo and Oduro (2013) stated that the regular visitors of cocoa flowers belonged to Hymenoptera and Diptera. Hymenoptera and Diptera are the two most important groups of pollinators (Stojnic et al. 2012). The dominant insects that pollinate cacao flowers belong to the orders Diptera and Hymenoptera (Bashir et al. 2019). Crop pollination by pollinators is an important ecosystem service, as shown in coffee (*Coffea* sp.) and cocoa, two major insect-pollinated tropical plantation crops. Pollination in cocoa has been evaluated as the most significant limiting factor in cocoa yield than agronomic resources (Bakar and Awang 2018). Widhiono et al. (2016) found many wild bees on Mount Slamet. Wild bee diversity in habitats with few wild plant species strongly correlated with wild plant diversity, whereas in habitats with high wild plant species richness, flowering plant abundance became more important.

Similar to predators, parasitoid insects also play a role in regulating the balance in nature. In the cocoa plantations of the Saiyo and Manunggang Sakato, parasitoids from the Tachinidae were identified with the highest number of parasitoids. Meanwhile, parasitoids identified from Bungo Tanjung Sepakat came from the Ichneumonidae. Audi and Biliyaminu (2018) stated that all tachinid flies are larval parasitoids of insects. Ichneumonids utilize a diverse group of insects as their hosts and play an essential role in the biological control of insects. Parasitoids from Tachinidae and Ichneumonidae play a role in controlling pests on cocoa plants. One of the species from the Ichneumonidae, *Goryphus mesoxanthus*, is a natural enemy of Cocoa Pod Borer.

In addition to insects that play a role in agriculture, both positive and negative roles, mosquito species from the Culicidae was also identified as other insects. Mosquitoes are vectors that carry various types of diseases, so their presence is considered harmful to humans, but mosquitoes also have an important role in the food chain in the ecosystem. Mosquito larvae are food for dragonfly nymphs, while dragonfly adults are predators for various pests (Vatandoost 2021).

Insect diversity

The insect diversity index in the three locations ranged from 2.09 to 3.15, which was included in the medium category. The highest index was found in the cocoa plantations of the Manunggang Sakato (3.15), and the lowest index was found in the cocoa plantations of the Bungo Tanjung Sepakat (2.09). The insect diversity index can be seen in Figure 6.

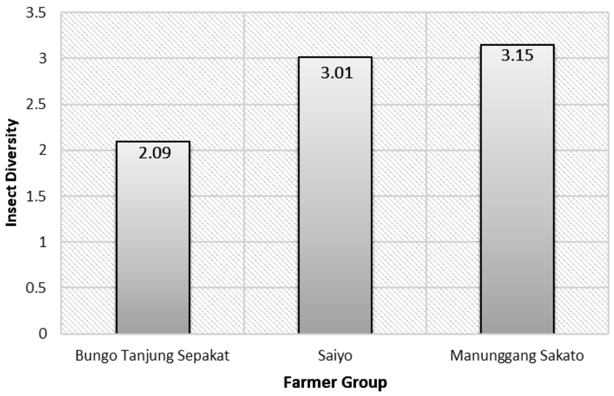

Figure 6. Insect diversity Index in three locations at Salayo Cocoa Plantation

Correlation between farmer behavior and insect diversity

The correlation between farmers' behavior in cocoa management and insect diversity was analyzed by the Pearson analysis method using the SPSS 16 program. Pearson analysis was carried out on normally distributed data, so before the correlation analysis, a test was conducted to see the normality of the data distribution. Tests were carried out using Shapiro-Wilk analysis. The p-value for the variables of farmer behavior in pesticide application, sanitation, and pruning, as well as insect diversity, was greater than 0.05, so it can be concluded that the data are normally distributed, and Pearson correlation analysis could be performed (Table 6).

From the three of farmer behavior, insect diversity was strongly correlated with behavior in terms of pesticide application and land sanitation (Table 7). Extensive use of chemical pesticides can negatively affect insect diversity. Good behavior of farmers in pesticide application, among others, by not making pesticides the main choice in controlling cocoa plant pests, pesticide application is carried out according to the dosage listed and adjusted to the number of pests and diseases that will have a positive effect on insect diversity. The better the farmer's behavior in applying pesticides, the higher the diversity of insects. Ransford et al. (2021) stated that the absence of pesticide use in organic cocoa plantations has undoubtedly had a positive impact on natural enemy populations in organic cocoa plantations.

Farmers' behavior in sanitation by leaving 1 or 2 layers of litter will provide a suitable environment for various types of insects. The presence of litter will also provide a food source for insects. The leaf litter layer is an important habitat to many arthropods since they utilize it for food, shelter from environmental conditions, and protection from predators (Hamilton 2015). Elfaki et al. (2013) found leaf litter insects at Amani Nature Reserve, Tanzania, consisting of 8 different orders: Blattodea, Coleoptera, Collembola, Diptera, Hemiptera, Hymenoptera, Orthoptera, and Thysanura. Diptera had the highest abundance in the overall collection. Different results were found in the Salayo cocoa plantation; the insects with the highest abundance were from the order Hymenoptera.

Table 6. Data normality test

Variable	P Value	Description
Farmer behavior in pesticide application	0.363	Normal
Farmer behavior in sanitation	0.372	Normal
Farmer behavior in pruning	0.135	Normal
Insect diversity	0.233	Normal

Table 7. The correlation between farmer's behavior in cocoa management on insect diversity

Farmer's behavior	P value	Correlation to insect diversity
Applying pesticide wisely	0.043	0.998*
Doing land sanitation	0.047	0.997*
Pruning	0.544	0.656

Note: *Significant correlation at 5% significance level

Farmers' behavior in pruning related to increasing agricultural production is in the sufficient and good category (Table 1). However, in relation to insect diversity, it is suspected that it has the potential to reduce insect diversity, especially if the pruning is done excessively, causing the basic branching framework to be exposed and exposed to direct sunlight. Setyawan et al. (2020) stated that a higher canopy cover percentage (66.22%) in the mangrove ecosystem results in height insect diversity compared to a lower canopy cover percentage. Guillén et al. (2022) found that *Anastrepha obliqua* females prefer to oviposit in shaded areas with lower temperatures to avoid egg mortality due to desiccation or overheating. Cocoa pruning can positively affect insect diversity if followed by appropriate sanitation measures, namely, leaving one or two litter layers in cocoa plantations. Regular pruning makes the litter thick, and such conditions are conducive to insect breeding grounds. Pollinators are highly dependent on decaying organic materials, and the lack of substrates in the cocoa field may limit their population (Bakar and Awang 2018).

Generally, insects were found in Salayo Cocoa Plantation consisted of 11 orders, 31 families, 58 species, and 750 individuals. Species richness index was more than 4, included in the high category. The highest abundance of species found was *Dolichoderus thoracicus* (Hymenoptera: Formicidae) in Bungo Tanjung Sepakat, *Iridomyrmex* sp. in Saiyo, and *Anoplolepis* sp. in Manunggang Sakato. The insect diversity index ranged from 2.09-3.15, from moderate to high, which means moderate to a high diversity and steady ecosystem stability. Insects collected can be grouped as herbivores (pests), carnivores (predators and parasitoids), decomposers, pollinators, and others. Carnivore percentage was higher than herbivore. Farmers' behavior in pesticide application, sanitation and pruning has a correlation with insect diversity in cocoa plantations. The farmers in Manunggang Sakato have cultivated cacao well and very selective in applying pesticides than other locations and insect diversity in Manunggang Sakato cocoa plantation was higher than the other locations. Good farmer behavior in managing the cocoa plantation can maintain insect diversity and the sustainability of ecosystem services provided by insects.

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