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Insect Community Status in Different Field Conditions and Clones in Kaliwining Cocoa Experimental Station, East Java, Indonesia

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Abstract

Insect communities are vital to the ecological and economic success of cocoa agroforestry systems, providing essential functions such in pollination, pest control, and nutrient cycling. Their presence and performance are shaped by field structure, clone genetics, habitat complexity, and agricultural practices. This research was conducted at the Experimental Station of the Indonesian Coffee and Cocoa Research Institute in Jember, East Java, which focused on two distinct types of cocoa fields (differences in planting years, plant density, and shade trees) and clones (clone ICCRI03, ICCRI09, and MCC02). The research highlights are the role of field conditions and genetic factors in shaping insect diversity and abundance. The trapping method used a yellow trap, and field conditions included plant height, canopy width, and leaf litter amount, which were measured. The observation revealed 35 insect morphospecies from 30 families and eight non-insect morphospecies, emphasizing the functional diversity of these communities. Field conditions and clones did not have a significant effect on insect abundance and diversity. Field conditions, including plant height, canopy width, and leaf litter amount, did not show a strong correlation with the abundance of insects. Field with more shade trees and vegetation, had a greater abundance of insects, notably predators and decomposers. MCC02 favored pollinator populations, ICCRI03 boosted predators and parasitoids, and ICCRI09 increased overall diversity. However, pollinators and omnivores showed minimal variety across fields and clones. Shannon diversity index values (H' = 1.59-1.75) suggested moderate biodiversity with uneven species distribution. The study underscores the importance of maintaining habitat complexity, optimizing field management, and strategic clone selection to enhance ecosystem services like pollination and pest control while fostering biodiversity.

Keywords: Insect, cocoa, fields, clone, abundance, diversity

INTRODUCTION

Insect diversity was categorized into functional groups and used to assess the extent of ecosystem services provided on farms. The functional roles explored include recycling/detrivore, fungivore, predator, herbivore, scavenger, parasitoids, and ants that perform numerous functions at once. In this study, environmental quality was measured by the diversity of insects and other arthropods (arachnids and acarina), which account for 90% of all species' variability. Ecosystem structure is dominated by them (Pimentel *et al.*, 1992; Bellamy *et al.*, 2018), and explores the vast world of insects, which represent the pinnacle of biodiversity. Insects provide services such as organic matter breakdown, nutrient recycling, soil conditioning, and pest predation. Insects serve as pollinators and food sources for birds and mammals on a larger landscape scale. Less than 1% of the detected insects are pests (Verma *et al.*, 2023).

In a cocoa plantation, the cocoa ecology may sustain numerous insect groups, and the cocoa tree has a specific pollination mechanism (Adjaloo *et al.*, 2013). Cocoa flower pollination is complex and relies heavily on insect pollinators (Adjaloo *et al.,* 2013; Zakariyya *et al.*, 2016). Cocoa flowers have a distinctive structure that prevents natural pollination because the fertile stamens are blocked by sterile stamen structures known as staminodia. Furthermore, cocoa blooms lack a nectar-like aroma and have sticky pollen grains. As a result, natural pollination can only take place when insects burrow into the complicated floral structure (Dani & Rokhmah, 2022). A diverse range of insects are reported to visit the flowers of various cocoa species. While farmed cocoa blooms attract a variety of insect species (Toledo-Hernández *et al.*, 2017), natural populations are mostly frequented by Hymenoptera and Diptera (Chumacero de Schawe *et al.*, 2018). In Brazil, stingless bees like Plebeia minima and Trigonisca pendiculana have been spotted visiting *Theobroma grandiflorum* blooms (Venturieri *et al.*, 1995; Jaramillo *et al.*, 2024). In Ecuador, 68 insect morphospecies were observed, including just one Ceratopogonidae species, *Dasyhelea* sp., which visited *Theobroma bicolor* flowers (Ponce-Sánchez *et al.*, 2021). The variety of insects that visit Theobroma flowers suggests that cocoa blossoms may similarly attract a wide range of insects (Jaramillo *et al.*, 2024).

Conserving and restoring natural habitats, along with maintaining landscape diversity, promotes the growth of wild pollinator populations. This is especially crucial for cocoa production, which relies heavily on non-bee pollinators. A study conducted in Ghana found that the distance from cocoa farms to forests had no impact on either the number of midges present or the resulting cocoa fruit set (Frimpong *et al.*, 2011). A study in Indonesia found that the number of insects on flowers was not affected by how far the plantation was from a forest. Instead, it was influenced by increased canopy cover and the presence of potential pollinator habitats, such as leaf litter and secondary forests, in the area surrounding the plantation (Toledo-Hernández *et al.*, 2021). A clear positive relationship exists between pollinator numbers and cocoa tree density, leaf litter cover, and decomposing fruit on the ground. Conversely, the presence of timber, banana, fruit, and palm trees, as well as stones, grass, and bare soil, negatively impacted pollinator abundance. The negative effect of canopy vegetation seems related to excessive shade rather than simply the quantity of plants (Córdoba *et al.*, 2013).

The types of crop varieties (cultivars) grown can also affect insect communities. According to research (Prasifka *et al.*, 2018; Stejskalová *et al.*, 2018; Burns & Stanley, 2022; Tscharntke *et al.*, 2024), pollinator species exhibit preferences for particular crop varieties. For example, the roles of both wild and managed insect pollinators in apple pollination are influenced by the specific apple cultivar (Burns & Stanley, 2022). Pollinator identification and community composition can also vary significantly over area and time (Winfree *et al.*, 2015). In concrete terms, pollen genotypes may differ depending on pollinator species, especially if movement patterns are unique to each other. As a result, pollinator identification can affect fruit quality because the source of pollen (i.e. pollen parentage) is well known to influence this trait, a phenomenon known as "xenia" (Tscharntke *et al.*, 2024). Based on these references, by conducting this research, the effect of several planted cacao clones on the insect community will be investigated, especially the community of pollinators. This research aims to examine the status of the insect community in two different cocoa fields and three different cocoa clones. It looks further into the effect of cocoa field conditions, such as planting density, shade trees, plant height, canopy width, and leaf litter, on the abundance and diversity of insects.

MATERIALS AND METHODS

This research, meticulously conducted at the Experimental Station of ICCRI in Jember, East Java, focused on two cocoa fields which have differences in area size, planting year, plant density, planted shade trees, and shade tree density. The difference between these two blocks is shown in Table 1. Every field consisted of plots of three chosen clones (clone ICCRI03, ICCRI09, and MCC02), and every plot was repeated three times. Field effect and clones are factors for this research.

Insect trapping was conducted by installing yellow sticky traps. Tscharntke *et al.* (2024) stated that yellow sticky traps are an effective and low-cost method for monitoring various insect populations in agricultural areas. In this research, the yellow trap was constructed from 1-liter transparent bottles that were yellow painted and then covered with a transparent plastic sheet coated with insect glue. The trap is then hung on a tree branch with abundant flowers, at a height of 1.5 meters from the ground. The tree is located at the center of the plot of the selected clone. The traps are kept in place for 24 hours (8 am to 8 am), then the transparent plastic sheets that trapped insects are collected in the laboratory for examination. Insect trapping was only done once.

Trapped insects were then identified to the morphospecies level in Pasuruan Cocoa Technical Centre's Laboratory. Morphospecies are taxonomic units recognized based on morphological differences and are used as substitutes for species names in bio-diversity studies (Ikhsan *et al.*, 2020). The identification process includes the following steps: 1) Morphological observation by observing the morphological characteristics of the arthropods using a microscope and documenting the findings with a camera of Microscope Stereo Olympus SZX7. 2) Matching morpho-logical features with databases by comparing the documented morphological features of the insects with the database available on the Pollination Guelph website and the Pollinator Identification database (Pollination Guelph), as per the study by Windriyanti *et al.* (2023). Additionally, use the Barcode of Life Data System (BOLD Systems) website to determine the morphospecies of each individual. For confirming the role of insects, those two websites are used and other official websites such as britannica.com/animal/insect, bugguide.net and other related articles.

Table 1. The difference between the two-field observation

Parameters	Field A	Field B
Area size	0.83 ha	0.50 ha
Planting year	2017 (7 years)	2018 (6 years)
Plant density	896 plants	508 plants
Shade Trees	*Leucaena sp.* with a population of 841 plants.	*Leucaena* sp. with a population of 150 plants.*Piper nigrum* with a population of 150 plants.

Table 2. Climate data of the experimental plantation of Kaliwining during the observation

Date	Temperature (°C)	RelativeSolar humidity (%)	Radiation (W/m^2)	Wind speed (m/s)	Rain (mm)
28-29 May 2024 (During Trapping Time) *	27.20	87.26	191.25	0.34	0.00
01-31 May 2024 (Whole month)	26.78	87.50	184.65	0.39	67.00

In this project, the impact of canopy height and soil leaf litter amount is also emphasized. Canopy height measurement was conducted by measuring the highest point of growth of the primary stem from the ground or the basal stem. Canopy width was measured by measuring the diameter of the canopy and an angle (east to west and north to south). Soil leaf litter amount was measured under the canopy of sample trees by plotting 2 m x 2 m (4 m^2) as many as eight points in each observation block, then all leaf litters in every plot were measured and expressed in kilograms. Climate data such as temperature, humidity, wind speed, rainfall, and solar radiation (Table 2) were taken from the weather station of the experimental plantation of Kaliwining. Statistical study of insect population parameters was performed by using analysis of variance at a 95% through General Linear Models (GLMs) in the GenStat program. If the treatment has a significant effect, Tukey's test (D = 5%) might be used for additional analysis (Gomez and Gomez, 1984). Biodiversity index was performed by using Diversity Indices analysis in the Genstat program.

RESULTS AND DISCUSSION

Insects that have been collected during the observation in two fields with three different clones resulted in the identification of 35 morphospecies, of which eight belong to Araneae or non-insect. Those 35 insect morphospecies belong to 30 families: Acrididae, Aphididae, Cecidomyiidae, Ceraphronidae, Ceratopogonidae, Chaoboridae, Chironomidae, Cicadellidae, Coccinellidae, Culicidae, Curculionidae, Diapriidae, Diocidiidae, Drosophilidae, Ectobiidae, Encyrtidae, Fanniidae, Formicidae, Ichneumonidae, Ismaridae, Mycetophilidae, Orchesellidae, Phoridae, Platygastridae, Ptinidae, Rhaphidophoridae, Silvanidae, Sphecidae, Trichogrammatidae, and Triozidae. Then, for eight araneae's morphospecies belong to 8 families: Araneidae, Cheiracanthiidae, Linyphiidae, Oxyopidae, Pacullidae, Tetragnathidae, Theridiidae, and Viridasiidae. This result is shown in Tables 3 and 4.

Field A, with 896 cocoa plants and a dense shade canopy of 841 *Leucaena* sp. trees, produces a unique microhabitat that supports increased abundance of predatory morphospecies like *Chaorobus flavicans* (1.33±1.5) and *Mangora* sp. (0.66±1.15 under MCC02). Predators are likely to benefit from the dense canopy's shelter and consistent microclimate. These findings are consistent with Blaser *et al.* (2017), who discovered that dense shade enhances habitat conditions for beneficial insects by lowering temperature changes and boosting humidity. Field B, with fewer shade trees (*Leucaena* sp. and *P. nigrum*), has a somewhat higher abundance of pollinators such as *Placochela* sp. (0.44±0.52 under ICCRI09 and MCC02), probably due to enhanced light availability and floral resources from the diversified shade species.

If we place more emphasis on clone effect size, the varied patterns of insect abundance and diversity observed in clones ICCRI03, ICCRI09, and MCC02 highlight the importance of plant genotype in shaping ecosystem services. For example, MCC02 promotes higher pollinator populations, which improves

Table 3. Average of insect abundance in three different clones in Field A (7 years old)

Ordo	Family	Morphospecies	Role	Clone			Average
				ICCRI03	ICCRI09	MCC02	
Araneae	Araneidae	*Mangora* sp.	Predator	0.00±0.00	0.00±0.00	0.66±1.15	0.22±0.66
	Cheiracanthiidae	*Strotarchus* sp.	Predator	1.00±1.73	0.00±0.00	0.33±0.57	0.44±1.01
	Linyphiidae	*Unknown species*	Predator	0.16±0.40	0.00±0.00	0.16±0.40	0.11±0.32
	Oxyopidae	*Oxyopes* sp.	Predator	0.33±0.57	0.33±0.57	0.00±0.00	0.22±0.44
	Pacullidae	*Unknown species*	Predator	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
	Tetragnathidae	*Tetragnatha* sp.	Predator	0.00±0.00	0.00±0.00	0.33±0.57	0.11±0.33
	Viridasiidae	*Vulsor sp.*	Predator	0.33±0.57	0.00±0.00	0.00±0.00	0.11±0.33
Blattodea	Ectobiidae	*Plununcus* sp.	Decomposer	0.33±0.57	0.00±0.00	0.00±0.00	0.11±0.33
Coleoptera	Ptinidae	*Lasioderma* sp.	Herbivore	0.33±0.57	0.33±0.57	0.00±0.00	0.22±0.44
Diptera	Cecidomyiidae	*Placochela* sp.	Pollinator	0.33±0.57	1.00±1.00	0.00±0.00	0.44±0.72
	Ceratopogonidae	*Forcipomyia* sp. *DB 11422*	Pollinator	0.33±0.57	0.66±1.15	1.00±1.73	0.66±1.11
	Chaoboridae	*Chaoborus* sp.	Predator	1.66±2.08	1.66±1.52	0.66±1.15	1.33±1.5
	Chironomidae	*Chironomus sp.*	Habitat Indicator	0.00±0.00	0.00±0.00	0.66±1.15	0.22±0.66
		Unknown species	Habitat Indicator	1.33±1.52	0.66±0.57	0.66±1.15	0.88±1.05
	Cicadellidae	*Eremochlorita* sp.	Herbivore	0.33±0.57	0.33±0.57	0.33±0.57	0.33±0.5
	Culicidae	*Culex* sp.	Habitat Indicator	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
	Diocidiidae	*Diadocidia* sp.	Decomposer	0.00±0.00	0.00±0.00	0.33±0.57	0.11±0.33
	Mycetophilidae	*Phthinia* sp.	Decomposer	0.00±0.00	0.00±0.00	0.66±1.15	0.22±0.66
	Phoridae	*Enderleinphora* sp.	Decomposer	1.66±1.52	1.66±1.52	1.66±1.52	1.66±1.32
Entomobryomorpha	Orchesellidae	*Orchesella* sp.	Omnivore	0.33±0.57	0.66±0.57	0.66±1.15	0.55±0.72
Hemiptera	Aphididae	*Macrosiphum* sp.	Herbivore	0.00±0.00	0.00±0.00	0.33±0.57	0.11±0.33
	Triozidae	*Heterotrioza* sp.	Herbivore	0.00±0.00	0.00±0.00	0.66±1.15	0.22±0.66
Hymenoptera	Diapriidae	*Cinetus* sp.	Parasitoid	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
	Encyrtidae	*Ageniaspis* sp.	Parasitoid	0.66±0.57	0.00±0.00	0.33±0.57	0.33±0.50
		EncyrMalaise01 sp.	Parasitoid	0.00±0.00	0.66±1.15	0.66±1.15	0.44±0.88
	Formicidae	*Dolichoderus* sp.	Parasitoid	2.00±3.46	0.33±0.57	1.00±1.73	1.11±2.08
	Ichneumonidae	*Gelis* sp.	Parasitoid	0.00±0.00	0.00±0.00	0.33±0.57	0.11±0.33
	Ismaridae	*Ismarus* sp.	Parasitoid	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
	Platygastridae	*Gryon* sp.	Parasitoid	0.33±0.57	0.00±0.00	0.00±0.00	0.11±0.33
Orthoptera	Acrididae	*Valanga* sp.	Herbivore	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
	Rhaphidophoridae	*Diestramima* sp.	Decomposer	0.00±0.00	0.00±0.00	0.66±1.15	0.22±0.66
8	29	31		0.36±0.94	0.31±0.66	0.38±0.79	0.35±0.80

pollination services. *Forcipomyia* sp. (Ceratopogonidae) shows its highest abundance in MCC02 (1±1.73), suggesting that this clone may offer favorable floral resources or microhabitat conditions. Similarly, *Placochela* sp. (*Cecidomyiidae*) is more abundant in ICCRI09 (1±1) compared to other clones. These findings are related to Vansynghel *et al.* (2022) regarding flower insect visitors are assumed as cacao pollinators, who discovered that among all the visitors, 7% were midges (*Ceratopogonidae* and *Cecidomyiidae*), thought to be responsible for cacao pollination. Further research needs to be done to confirm that certain types of insects that visit are influenced by the characteristics of a particular cocoa clone, such as floral odor and color. Arnold *et al.* (2019) stated that the scents emitted by cacao flowers are important for attracting or guiding pollinators. Blaser *et al.* (2017) also highlighted those differences in cacao flower structure and nectar composition across clones influence pollinator attraction and consequently crop productivity. On the other hand, ICCRI03 boosts predator and parasitoid numbers, which aids in pest control. These clone-specific effects indicate that strategic clone selection can optimize numerous ecosystem services, as reported by Mortimer *et al.* (2018), who found that genotypebased management strategies improve both ecological balance and cacao yield.

The results of analysis of variance (ANOVA) from Table 5 reveal how field conditions, cacao clones, and their interaction influence the abundance of insects across different functional roles (Decomposer, Habitat Indicator, Herbivore, Omnivore, Parasitoid, Pollinator, Predator, and total insects), providing insights into the ecological dynamics in cacao agroforestry systems. Table 5 indicates the significance levels of field and clone effects on various insect roles, while Tables 6 and 7 present detailed averages of insect abundance across different roles. Based on Table 6, significance only happened in three functional groups, including Herbivores (Fpr = 0.03), Omnivores (Fpr = 0.02), and Pollinators (Fpr = 0.04), which are influenced by field conditions.

The results demonstrate that field conditions significantly affect the abundance of several insect roles, particularly herbivores and omnivores. Field A exhibited a higher total insect abundance (11.30±3.65) compared to Field B (8.00±3.39), suggesting that the more shaded conditions in Field A, with denser vegetation, provide a more suitable habitat for a diverse insect community (Vandromme *et al.*, 2023). Herbivores were significantly more abundant in Field B (3.44±2.26) compared to Field A (0.88±0.73), likely due to the higher exposure to sunlight and reduced shade in Field B, which might promote plant growth and attract herbivorous insects. For strengthening these results, further observations related to microclimate in both blocks need to be carried out to see the differences such as data temperature and relative humidity under the canopy.

The data from Tables 5 and 6 reveal that pollinator abundance is significantly influenced by the field factor (p = 0.04). Field A showed a notably higher abundance of pollinators (1.11±0.99) compared to Field B (0.22±0.41), emphasizing the role of environmental conditions in shaping pollinator communities. These findings align with previous studies indicating that habitat complexity and microclimatic conditions directly affect pollinator populations (Tscharntke *et al.*, 2012). Field A, with denser shade trees and a more diverse vegetation structure, likely provides better foraging resources, nesting sites, and protection for pollinators. Research by Vandromme *et al.* (2023) supports the idea that shaded environments in agroforestry systems enhance the abundance and diversity of pollinators by mimicking natural habitats. The significantly lower pollinator abundance in Field B (0.22±0.41)

Table 4. Average of insect abundance in three different clones in Field B (6 years old)

Ordo	Family	Morphospecies	Role	Clone			Average
				ICCRI03	ICCRI09	MCC02	
Araneae	Araneidae	*Cyclosa* sp.	Predator	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
	Cheiracanthiidae	*Strotarchus* sp.	Predator	0.33±0.57	0.00±0.00	0.00±0.00	0.11±0.33
	Oxyopidae	*Oxyopes* sp.	Predator	0.00±0.00	0.00±0.00	0.33±0.57	0.11±0.33
	Theridiidae	*Exalbidion* sp.	Predator	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
Blattodea	Ectobiidae	*Plununcus* sp.	Decomposer	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
Coleoptera	Coccinellidae	*Coccidulini* sp.	Predator	0.66±1.15	0.33±0.57	0.00±0.00	0.33±0.70
	Curculionidae	*Unknown Spesies 2*	Herbivore	0.33±0.57	0.00±0.00	0.00±0.00	0.11±0.33
	Silvanidae	*Oryzaephilus* sp.	Herbivore	0.33±0.57	0.00±0.00	0.00±0.00	0.11±0.33
Diptera	Cecidomyiidae	*Placochela* sp.	Pollinator	0.00±0.00	0.66±0.57	0.66±0.57	0.44±0.52
	Ceratopogonidae	*Forcipomyia* sp. *5ES*	Pollinator	0.00±0.00	0.00±0.00	0.33±0.57	0.11±0.33
		Forcipomyia sp. *DB 11422*	Pollinator	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
Chaoboridae	*Chaoborus flavicans*	Predator	0.33±0.57	0.66±0.57	1.00±1.00	0.66±0.70	
	Drosophilidae	*Scaptodrosophila* sp.	Decomposer	0.00±0.00	0.00±0.00	0.33±0.57	0.11±0.33
	Fanniidae	*Fannia* sp.	Decomposer	0.33±0.57	0.00±0.00	0.33±0.57	0.22±0.44
	Mycetophilidae	*Phthinia* sp.	Decomposer	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
	Phoridae	*Enderleinphora* sp.	Decomposer	0.66±0.57	0.00±0.00	0.00±0.00	0.22±0.44
		Unknown Spesies 3	Decomposer	0.33±0.57	0.33±0.57	0.33±0.57	0.33±0.5
Entomobryomorpha	Orchesellidae	*Orchesella sp.*	Omnivore	0.33±0.57	0.66±1.15	1.33±1.52	0.77±1.09
Hemiptera	Triozidae	*Casuarinicola* sp.	Herbivore	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
		Heterotrioza sp.	Herbivore	2.00±1.00	2.00±1.00	1.66±2.08	1.88±1.26
Hymenoptera	Ceraphronidae	*Aphanogmus* sp.	Parasitoid	0.33±0.57	0.66±1.15	2.00±1.73	1.00±1.32
	Diapriidae	*Belytini* sp.	Parasitoid	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
	Formicidae	*Dolichoderus* sp.	Predator	0.00±0.00	0.33±0.57	0.00±0.00	0.11±0.33
	Sphecidae	*Chalybion* sp.	Parasitoid	1.00±1.73	0.00±0.00	0.00±0.00	0.33±1.00
	Trichogrammatidae	*Paracentrobia* sp.	Parasitoid	0.33±0.57	0.00±0.00	0.33±0.57	0.22±0.44
7	22	25		0.29±0.65	0.32±0.61	0.34±0.81	0.32±0.69

Table 5. The significance analysis of the field and clone effect on the abundance of insect's role and total individual

Variance	df	Decomposer		Habitat Indicator		Herbivore		Omnivore		Parasitoid		Pollinator		Predator		All Insects	
		LSD	Fpr	LSD	Fpr	LSD	Fpr	LSD	Fpr	LSD	Fpr	LSD	Fpr	LSD	Fpr	LSD	Fpr
Field	1	1.77	0.12	1.27	0.06	2.28	0.03	0.51	0.02	1.91	0.53	0.84	0.04	1.87	0.18	4.69	0.15
Clone	2	2.17	0.61	1.55	0.96	2.79	0.79	0.62	0.51	2.33	0.67	1.02	0.39	2.29	0.70	5.75	0.84
Field x Clone	2	3.06	0.67	2.20	0.96	3.94	0.86	0.88	0.51	3.30	0.81	1.45	0.71	3.24	0.80	8.13	0.90

Table 6. The average of insec abundance based on the role which is affected by different field conditions.

Field	Decomposer	Habitat Indicator	Herbivore	Omnivore	Parasitoid	Pollinator	Predator	All Insects
Field A	2.33±2.00	1.22±1.31	0.88±0.73A	0.66±0.66B	2.33±1.88	1.11±0.99B	2.77±1.68	11.30±3.65
Field B	1.00±0.66	0.00±0.00	3.44±2.26B	0.00±0.00A	1.77±1.22	0.22±0.41A	1.55±1.16	8.00±3.39
Average	1.66±1.63	0.61±1.11	2.16±2.11	0.33±0.57	2.05±1.61	0.66±0.88	2.16±1.57	9.66±3.90

Note: Bold means are significantly affected by factor and means values followed by the same letter in the same column is not significantly different from level of 5% according to the duncan multiple distance test.

Table 7. The average of insect's abundance based on the role which is affected by different clones.

Clone	Decomposer	Habitat Indicator	Herbivore	Omnivore	Parasitoid	Pollinator	Predator	All Insect
ICCRI03	1.66±1.10	0.66±1.10	1.66±1.59	0.16±0.37	2.33±2.49	0.33±0.47	2.66±2.28	9.50±3.59
ICCRI09	1.16±1.06	0.50±0.50	2.33±1.97	0.50±0.50	1.50±0.76	1.00±0.81	2.00±1.00	9.00±2.94
MCC02	2.16±2.26	0.66±1.49	2.50±2.56	0.33±0.74	2.33±0.74	0.66±1.10	1.83±0.89	10.5±4.78
Average	1.66±1.63	0.61±1.11	2.16±2.11	0.33±0.57	2.05±1.61	0.66±0.88	2.16±1.57	9.66±3.90

suggests that simplified landscapes with less vegetation can lead to a decline in pollinator populations. This is consistent with studies showing that open and less shaded areas often lack the floral resources and microhabitats necessary for pollinator survival (Vansynghel *et al*., 2022).

Clone-specific differences were less noticeable compared to field effects (Table 5). However, insect abundance varied slightly among clones (Table 7). Clone MCC02 had the highest total insect count (10.5), especially for herbivores (2.50), decomposers (2.16), and parasitoids (2.33). This suggests it may be more attractive to insects due to its traits (Schowalter *et al*., 2018). Clone ICCRI09 had fewer insects overall (9.00) but slightly more habitat indicators (0.50) and pollinators (1.00). Clone ICCRI03 showed a balance between parasitoids and predators, suggesting it could be useful in pest management.

Field and clone interactions weren't statistically significant (Table 5), but the slight variations among clones across fields highlight the importance of both environment and genetics. For instance, MCC02 consistently supported more insects, regardless of the field, indicating its adaptability. Optimizing field conditions like vegetation and shade could increase insect numbers and variety.

Statistical analysis showed that field conditions, cocoa clones, and their interaction didn't significantly affect insect diversity (Table 9). The Shannon diversity index (H') values (Tables 10 &11) show moderate diversity in insect communities across fields and clones. Table 10 shows that Field A (H' = 1.75) and Field B (H' = 1.59) both fall in the moderate range ($1 \leq H' \leq 3$), suggesting balanced communities with multiple species, but uneven abundance, aligning with Tassoni *et al*. (2024). In accordance with Ulfah *et al*., (2019) stated the diversity index in the mild category, in the sense that the ecosystem is still in a stable condition.

Based on Table 11, clones (ICCRI03: H' = 1.60, ICCRI09: H' = 1.75, MCC02: H' = 1.67) also had moderate diversity. ICCRI09's higher diversity may support more balanced insect communities, especially for herbivores and parasitoids, possibly due to genetic traits (Gols & Harvey, 2023). MCC02 had a slightly lower total H' but the highest decomposer diversity (H' = 0.29), indicating a role in nutrient cycling. Pollinators and omnivores showed zero diversity across all clones, suggesting a system-wide issue possibly due to monoculture and lack of resources (Asmah *et al*., 2017).

A concern is the zero diversity of omnivores and pollinators across all clones and fields. Lack of variety in cacao fields may limit resources like prey or nesting sites for omnivores (Andersson *et al*., 2014). Pollinators need floral resources like nectar and pollen. The absence of flowering plants near cacao plantations can lead to a lack of pollinators (Winfree *et al*., 2015). Pollinators also depend on microhabitats like leaf litter and shaded areas. Simplified farms with less complexity fail to support these habitats (Blaser *et al*., 2017).

The Bray-Curtis similarity index (SI) measures how similar insect communities are. Table 8 shows varying degrees of similarity among insect communities across fields and clones, giving insight into how environment and genetics affect insect diversity. The Bray-Curtis similarity index between Field A and Field B is 0.29, indicating low similarity in insect composition. Field A likely has more resources or habitat complexity, fostering a different community than Field B. This aligns with Lucatero *et al*. (2024), who showed that habitat complexity and management practices can lead to different insect communities in farms. Also, the number of morphospecies in Field A and Field B combined (174) and

Table 8. The Bray-Curtis similarity index (SI) of insects between two fields and three clones

Parameters	Field	Clone		
	Field A vs Field B	ICCRI03 vs ICCRI09	ICCRI03 vs MCC02	ICCRI09 vs MCC02
Number of Species A + B —etc	174	111	120	117
Number of Similar Morphospecies	88	85	93	90
Similarity Index (SI)	0.29	0.6	0.57	0.66

the shared morphospecies (88) reflect a relatively small overlap, further emphasizing environmental impacts. Asmah *et al.* (2017) highlight that less vegetation variety in monoculture systems can limit shared morphospecies across fields.

From a clone perspective, ICCRI09 and MCC02 show the most similarity (SI = 0.66). They share 90 out of 117 total insect species, suggesting they have common traits that attract similar insects. Genetic similarities between these clones could lead to comparable insect communities, as plant genetics can influence pollinator and herbivore communities (Mertens *et al.*, 2021). A further observation needs to be conducted to confirm the difference between clones such as canopy structure and leaf density which may affect the insect community.

These factors didn't significantly affect insect abundance (Fpr > 0.05). A) In Field A, there was a very weak positive relationship between plant height and insect abundance ($R^2 = 0.004$). B) Similarly, in Field B, the relationship between plant height and insect abundance was very weak ($R^2 = 0.009$). C) Canopy width in Field A showed a weak positive relationship with insect abundance ($R^2 = 0.009$), but more expansive canopies tended to have fewer insects. D) Field B showed a weak positive association between canopy width and insect abundance ($R^2 = 0.072$). E) Leaf litter in Field A had a weak relationship with insect abundance ($R^2 = 0.036$). F) Field B showed a higher correlation ($R^2 = 0.32$), suggesting leaf litter provides a more beneficial habitat for insects.

Statistical analysis indicates that the correlation between field conditions (plant height, canopy width, and leaf litter) and insect abundance is not significant (Fpr > 0.05). However, canopy width in Field A shows the strongest correlation (R2 = 0.349) (Figure 1A), suggesting that increased canopy width in Field A leads to a decrease in insect abundance. This aligns with Tscharntke *et al.* (2012), who stated that more expansive canopies reduce sunlight, limiting resources for insects like understory plants.

Leaf litter in Field B also shows a strong positive association with insect abundance (R2 = 0.32) (Figure 1F), possibly indicating a more beneficial habitat. Camargo-Vanegas *et al.* (2024) note that leaf litter provides shelter, moisture, and protection for insects like beetles, ants, and springtails. Grimbacher *et al.* (2018) found that beetle and ant populations correlated positively with litter volume, indicating increased habitat and resources.

The weak correlation between plant height and insect abundance suggests that plant height alone isn't a key factor in insect distributions. Other factors like leaf litter, canopy width, and floral resources likely play a more critical role. Future studies should consider these variables for a better understanding of insect communities. Leal *et al.* (2016) highlight that vegetation structure (plant density and diversity) has a more substantial effect on insect populations than plant height. Enhancing plant species richness and diverse vegetation structures may be more effective than focusing solely on plant height for influencing insect abundance.

Table 9. The significance analysis of the field and clone effect on Shannon diversity index of insect's role and total individual

Variance	df	Decomposer		Habitat Indicator		Herbivore		Omnivore		Parasitoid		Pollinator		Predator		Total Insects	
		LSD	Fpr	LSD	Fpr	LSD	Fpr	LSD	Fpr	LSD	Fpr	LSD	Fpr	LSD	Fpr	LSD	Fpr
Field	1	0.42	0.85	0.34	0.25	0.47	0.05	0.00	0.00	0.44	0.89	0.00	0.00	0.50	0.77	0.37	0.35
Clone	2	0.51	0.44	0.40	0.30	0.58	0.61	0.00	0.00	0.54	0.57	0.00	0.00	0.61	0.69	0.45	0.76
Field x Clone	2	0.72	0.94	0.40	0.43	0.82	0.63	0.00	0.00	0.76	0.47	0.00	0.00	0.86	0.54	0.64	0.74

Table 10. The average of insect diversity based on the role which is affected by different field conditions.

	Shannon Diversity Index (H')							
Field	Decomposer	Habitat Indicator	Herbivore	Omnivore	Parasitoid	Pollinator	Predator	All Insect
Field A	0.19±0.39	0.11±0.33	0.07±0.23	0.00±0.00	0.27±0.33	0.00±0.00	0.41±0.41	1.75±0.23
Field B	0.15±0.30	0.00±0.00	0.54±0.54	0.00±0.00	0.24±0.54	0.00±0.00	0.34±0.42	1.59±0.34
Average	0.17±0.34	0.05±0.23	0.31±0.46	0.00±0.00	0.25±0.43	0.00±0.00	0.38±0.41	1.67±0.29

Table 11. The average of insect diversity based on the role which is affected by different clone.

	Shannon Diversity Index (H')							
Clone	Decomposer	Habitat Indicator	Herbivore	Omnivore	Parasitoid	Pollinator	Predator	All Insect
ICCRI03	0.22±0.34	0.00±0.00	0.15±0.38	0.00±0.00	0.27±0.31	0.00±0.00	0.51±0.42	1.60±0.27
ICCRI09	0.00±0.00	0.00±0.00	0.38±0.60	0.00±0.00	0.37±0.65	0.00±0.00	0.32±0.35	1.75±0.31
MCC02	0.29±0.47	0.16±0.40	0.39±0.44	0.00±0.00	0.11±0.28	0.00±0.00	0.29±0.48	1.67±0.32

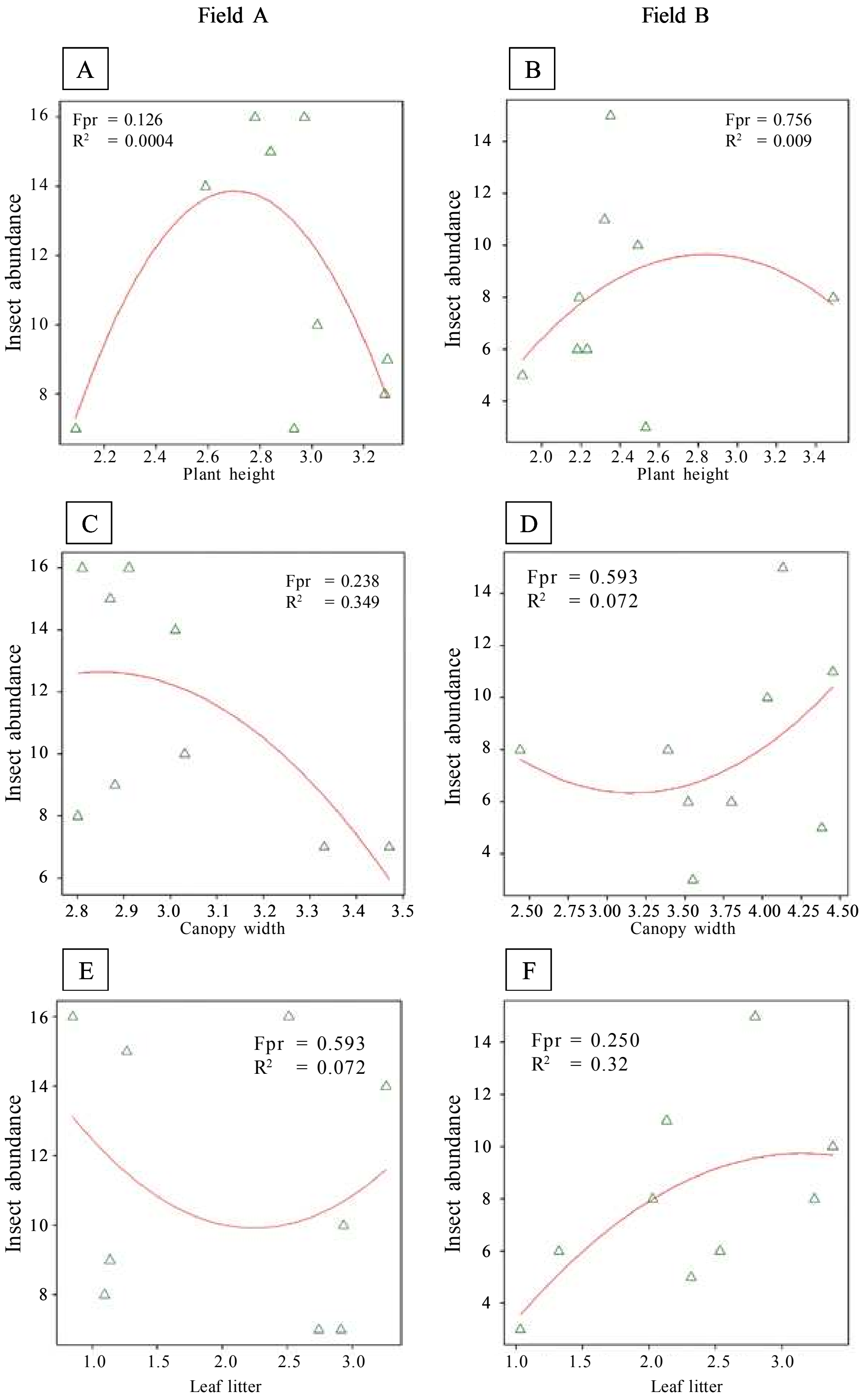

Figure 1. Shows the relationship between plant traits (height, canopy width, and leaf litter) and insect abundance in two fields (A and B)

CONCLUSION

This study examines the relationships between environmental factors, cocoa plant genetics, and insect communities in cocoa farms. Field A, with more shade, has a higher overall insect count and a more stable environment. Field B, with less shade, attracts more herbivores because of increased sunlight. Different cocoa clones influence insect populations. MCC02 supports the most insects, while ICCRI09 promotes greater insect diversity. However, there's a lack of diversity among pollinators and omnivores, likely due to simplified habitats and insufficient flowers. The moderate Shannon diversity index (H' = 1.59-1.75) indicates somewhat balanced but uneven insect communities, influenced by both field conditions and cocoa clone characteristics. The findings suggest that managing shade levels, maintaining diverse habitats, and selecting specific cocoa clones can improve pollination, pest control, and overall biodiversity. Future studies should investigate the role of flowers and habitat diversity in supporting pollinator and omnivore populations.

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