



Comparative Analysis of Insect Pest Diversity in Cocoa (*Theobroma cacao* L.) Agroecosystems under Different Shade Tree Canopies: Papaya vs. Banana

¹Basroh Saepul Mubarak, ²Ramadhani Mahendra Kusuma, ³Noni Rahmadhini

^{1,2,3}Department of Agrotechnology, Faculty of Agriculture, Universitas Pembangunan Nasional “Veteran” Jawa Timur, Surabaya, Indonesia.

*Corresponding Author e-mail: ramadhani_mahendra.agro@upnjatim.ac.id

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Abstract: This study compared the pest insect community structure in cocoa plantations shaded by papaya and banana trees. The study was conducted from January to March 2025 using systematic sampling in six cocoa fields, consisting of three papaya-shaded and three banana-shaded plantations. In each field, 19 traps were installed, comprising nine yellow traps, nine pitfall traps, and one light trap, supported by visual observations. Pest insects were identified to the genus level, and community structure was assessed using diversity (H'), evenness (E'), richness (R'), and dominance (C') indices. Banana-shaded cocoa fields supported slightly more pest insect genera than papaya-shaded fields, with 22 and 21 genera recorded, respectively. Banana-shaded plots also showed higher diversity, evenness, and richness, accompanied by lower dominance. These patterns indicate that the denser banana canopy may create more heterogeneous microhabitat conditions that support a broader range of pest insects. Shade tree type influences pest insect community structure in cocoa plantations. Banana shade was associated with a more diverse and balanced pest insect community, whereas papaya shade showed relatively higher dominance, suggesting a greater risk of specific pest outbreaks. These findings highlight the importance of shade tree selection in integrated pest management, particularly for designing site-specific monitoring and targeted control strategies in cocoa plantations.

Keywords: Diversity; insect pests; shade trees

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INTRODUCTION

Cocoa agroecosystems commonly rely on shade trees to regulate microclimatic conditions and support plant growth. However, different shade tree species may create distinct habitat conditions that influence pest insect communities. Shade trees modify key environmental factors such as temperature, humidity, light intensity, radiation, and wind speed, which in turn affect insect diversity, distribution, and population dynamics (Kohl et al., 2024). In addition, cocoa agroforestry systems provide important ecosystem services, including biodiversity conservation, pollination support, and pest regulation, all of which are strongly influenced by the composition and functional traits of shade trees (Edelstein et al., 2025).

Cocoa (*Theobroma cacao* L.) is widely cultivated in agroforestry systems, where shade trees play a crucial ecological role. By moderating temperature, humidity, light availability, and wind exposure, shade trees influence ecological processes related to pest dynamics, soil fertility, water availability, and plant productivity (Schmidt et al., 2022). Shade trees can also reduce soil and air temperatures, limit radiation, and decrease wind speed beneath the canopy. These changes may reduce evaporation, maintain soil moisture, and lower plant water requirements, particularly during drought periods (Saleh, 2016). The presence and diversity of shade trees in cocoa agroecosystems have also been reported to enhance biodiversity, including insect

diversity, which contributes to ecosystem services such as natural pest control and pollination (Bisseleua et al., 2013).

The ecological effects of shade, however, depend strongly on the identity and structural characteristics of the shade tree species. Differences in canopy architecture, phenology, and spatial arrangement can alter microhabitat conditions, habitat heterogeneity, and resource availability for insects. Consequently, shade tree species may influence pest incidence, community composition, and species distribution. Previous studies have shown that shade management can significantly affect pest occurrence and crop performance, suggesting that shade selection may function as an ecological pest management strategy (Asitoakor et al., 2024). A well-managed shading system can help maintain ecological balance and reduce the dominance of pest species that thrive under hot and dry conditions.

Papaya (*Carica papaya* L.) and banana (*Musa paradisiaca* L.) are commonly used as shade trees in cocoa plantations. Nevertheless, these two species differ markedly in canopy architecture and microclimatic influence, which may lead to variation in habitat conditions and insect community structure. Most previous studies have examined general shade effects or complex multi-species shade systems, whereas direct comparisons between specific shade tree species, particularly papaya and banana, remain limited. Investigating these shade types is therefore important for understanding how contrasting canopy structures affect pest insect diversity and distribution in cocoa agroecosystems.

Assessing the diversity of key pest insects is essential for identifying variation among pest genera and for developing more effective and targeted pest management strategies. In cocoa agroforestry systems, differences in shade tree species may generate distinct microclimatic conditions and levels of habitat heterogeneity, thereby influencing resource availability, insect behavior, and population dynamics. These processes ultimately shape pest insect community composition. Therefore, this study aimed to compare the diversity, evenness, richness, and dominance of pest insect genera in cocoa plantations shaded by banana trees and those shaded by papaya trees, in order to evaluate how different shade tree types influence pest insect community structure in cocoa agroecosystems.

METHOD

Determination of Research Location and Insect Data Collection

This study was conducted from January to March 2025 at the Pasuruan Cocoa Technical Center (PCTC), owned by PT Mondelez International. Insect samples were collected from cocoa plantations located in Curahdukuh Village, Kraton District, Pasuruan Regency, Indonesia (112°50'3" E; 7°38'19" S). The cocoa plants observed in this study were in the vegetative growth phase and were approximately 8 months old. The shade trees consisted of papaya (*Carica papaya* L.) and banana (*Musa paradisiaca* L.), both estimated to be 10 months old. Papaya trees had an average height of 1.8–2.0 m, whereas banana trees averaged 3.4–3.6 m in height, resulting in distinct canopy structures.

Papaya and banana were selected as shade trees because they are commonly used in cocoa agroforestry systems and have contrasting canopy architectures that may influence microclimatic conditions and, consequently, pest insect communities. These species may also serve as alternative host plants or food sources for certain insects, thereby potentially affecting pest populations in cocoa plantations. Previous studies have shown that differences in shade tree species can modify habitat conditions, resource availability, and pest incidence. To minimize confounding effects,

the papaya- and banana-shaded plots were established within the same plantation area and shared similar environmental conditions, including soil type, topography, and elevation. Cocoa plant age and management practices, including fertilization, irrigation, and pest control, were also comparable across plots. Therefore, differences in pest insect diversity and distribution were expected to be primarily associated with shade tree type.

Insect sampling was conducted in cocoa plots shaded by papaya and banana trees. The open-field cocoa plantation comprised 192 cocoa trees planted at a spacing of 2 m, covering an area of 34 m × 38.75 m. Pest insect populations were recorded through direct visual surveys of individuals visible to the naked eye in the field. Visual observations were conducted three times per week, with each observation lasting 30 min per plot. Observations were carried out in the morning between 06:00 and 09:00, when insect activity is generally high, to maintain consistency across sampling events. The observations focused on the stems and leaves of cocoa plants.

Insect samples were collected using 19 traps installed in each plot, consisting of one light trap, nine yellow traps, and nine pitfall traps. Across six plots, this arrangement resulted in a total sampling effort of 912 trap-nights. The traps were positioned diagonally within each plot to ensure representative sampling coverage, with a distance of 2 m between traps. The sampling methods were selected to capture a broad range of pest insect taxa with different ecological behaviors. Yellow traps were used to attract and capture flying insects, particularly those responsive to visual cues such as color. Pitfall traps were used to collect ground-dwelling insects, whereas light traps were employed to sample nocturnal species. In addition, visual observations were conducted to record insects that may not be effectively captured by traps, particularly those inhabiting plant surfaces. The combination of these methods is widely used in entomological studies and provides a more comprehensive assessment of insect diversity and distribution.

This study employed a comparative field design involving two shade types, namely papaya and banana, with equal sampling effort applied to each treatment. Sampling plots were established systematically within each shade condition to ensure spatial representation. Although untreated control plots were not included, the comparison between shade types served as the primary analytical framework. Trap placement followed a standardized arrangement within each plot to minimize sampling bias.

Morphological Identification and Data Analysis

Pest insects collected during the study were identified to the genus level based on morphological characteristics using standard taxonomic keys and identification references. Genus-level identification was based on external morphological features, including head structure, abdominal shape, wing venation, and body size (Pratami et al., 2016). Insect identification followed *The Insects: An Outline of Entomology* (Gullan & Cranston, 2014) and *Identification Key of Insects* (Lilies S. et al., 1991).

Pest insect population data were analyzed using the Shannon–Wiener diversity index (H'), evenness index (E'), richness index (R'), and dominance index (C'). The Shannon–Wiener index (H') was used to evaluate overall diversity by considering both taxon richness and relative abundance. Evenness (E') was calculated to assess the distribution of individuals among taxa, while the richness index (R') was used to estimate taxon richness. The dominance index (C') was applied to determine the extent to which particular taxa dominated the insect community. The genus diversity index in cocoa plantation plots was calculated using the Shannon–Wiener index (H') (Tustiyani et al., 2020).

$$H' = - \sum \left(\frac{n_i}{N} \right) \left(\ln \frac{n_i}{N} \right)$$

Description:

H' : genus diversity index

n_i : Number of individuals from all genera

N : Total number of individuals from all genera

The evenness index assesses the uniformity of each genus within a given community. The evenness index can be calculated using the following formula (Wijayanto et al., 2022).

$$E = \frac{H'}{\ln S}$$

Description:

E : Diversity Index.

H' : Genus Diversity.

ln : Natural Logarithm.

S : Number of Genera.

The genus richness index is a quantitative measure that quantifies the difference in the number of genera within a particular community. The more genera found in a community, the higher the genus richness index. The genus richness index can be measured using a formula (Wijayanto et al., 2022).

$$R = \frac{S - 1}{\ln(N)}$$

Description:

R : Richness index of the lineage.

S : Number of genera.

ln : Natural logarithm.

N : Total observed individuals.

The dominance index in a cocoa plantation area is calculated using the Simpson formula. (Tustiyani et al., 2020).

$$C = \sum \left(\frac{n_i}{N} \right)^2$$

Description:

C : Dominance index

n_i : Number of individuals

N : Total number of individuals

RESULT AND DISCUSSIONS

Pest Insects Found on Cocoa Land

Pest insects found on cocoa plantations beneath papaya trees belong to 5 orders: Blattodea, Diptera, Hemiptera, Lepidoptera, and Thysanoptera. A total of 18 families were identified, namely Blattellidae, Agromyzidae, Cecidomyiidae, Ceratopogonidae, Culicidae, Drosophilidae, Tephritidae, Alydidae, Aphididae, Cicadellidae, Derbidae, Miridae, Psyllidae, Erebidae, Hesperidae, Ustyurtidae, Phlaeothripidae, and Thripidae. The pest insects successfully identified on the cocoa plantation under papaya trees consist of 21 genera: *Blattella*, *Liriomyza*, *Monardia*, *Culicoides*, *Culex*, *Scaptomyza*, *Bactrocera*, *Leptocorisa*, *Aphis*, *Dysaphis*, *Hyperomyzus*, *Empoasca*, *Proutista*, *Orthotylus*, *Psylla*, *Amata*, *Pelopidas*, *Ustyurtia*, *Klambothrips*, *Frankliniella*, and *Thrips*. The abundance of pest insects on the land is influenced by the vegetation

that serves as their food source. According to Elisabeth et al. (2021), the greater the vegetation in a habitat, the more food resources for herbivorous insects, resulting in their abundance. Environmental conditions that are conducive to insect reproduction can also influence the diversity of insect genera. Elisabeth et al. (2021) also found that insect species abundance is largely determined by reproductive activity, which is supported by suitable environmental conditions and the availability of food sources.

Pest insects found on cocoa farms beneath banana trees belong to 4 orders: Diptera, Hemiptera, Lepidoptera, and Thysanoptera. A total of 18 families were identified: Agromyzidae, Cecidomyiidae, Ceratopogonidae, Drosophilidae, Psychodidae, Tephritidae, Alydidae, Aphididae, Cicadellidae, Derbidae, Diaspididae, Oxycarenidae, Psyllidae, Scutelleridae, Erebididae, Hesperidae, Phlaeothripidae, and Thripidae. The pest insects on cocoa farms under banana trees consist of 22 genera: *Liriomyza*, *Monardia*, *Culicoides*, *Scaptomyza*, *Lutzomyia*, *Bactrocera*, *Leptocorisa*, *Aphis*, *Dysaphis*, *Hyperomyzus*, *Empoasca*, *Maiestas*, *Proutista*, *Comstockaspis*, *Oxycarenum*, *Psylla*, *Chrysocoris*, *Sphrageidus*, *Erionota*, *Klambothrips*, *Frankliniella*, and *Thrips*. The abundance of pest insect genera on cocoa farms under banana trees is not much different from the abundance of pest insect genera on cocoa farms under papaya trees. This is because both papaya and banana trees have broad canopies, which attract insects. In accordance with the statement of Aseran and Rizali (2022) that insects with a higher role as herbivores are found in the plant canopy. This is possible because all the activities of herbivorous insects occur within the plant canopy, either in search of food or shelter from the sun. The growth of insect populations that act as herbivores can also be driven by environmental variation in vegetation. According to Safitri et al. (2020) Vegetation greatly influences the composition and presence of insects in an ecosystem. The results of observations of insect pest genera in cocoa fields are presented in Table 1.

Table 1. Pest insect genus on cocoa land shaded by papaya trees and cocoa land shaded by banana trees

No.	Classification			Population	
	Order	Family	Genus	Papaya	Banana
1.	Hemiptera	Cicadellidae	<i>Empoasca</i>	360	232
2.			<i>Maiestas</i>	0	5
3.			<i>Hyperomyzus</i>	125	92
4.		Aphididae	<i>Aphis</i>	19	68
5.			<i>Dysaphis</i>	4	1
6.			<i>Proutista</i>	7	283
7.		Alydidae	<i>Leptocorisa</i>	12	9
8.		Psyllidae	<i>Psylla</i>	1	2
9.		Diaspididae	<i>Comstockaspis</i>	0	5
10.		Oxycarenidae	<i>Oxycarenum</i>	0	4
11.		Scutelleridae	<i>Chrysocoris</i>	0	11
12.		Miridae	<i>Orthotylus</i>	4	0
13.	Diptera	Cecidomyiidae	<i>Monardia</i>	43	83
14.		Ceratopogonidae	<i>Culicoides</i>	38	35
15.		Tephritidae	<i>Bactrocera</i>	12	22
16.		Agromyzidae	<i>Liriomyza</i>	9	23
17.		Drosophilidae	<i>Scaptomyza</i>	8	4
18.		Culicidae	<i>Culex</i>	6	0
19.		Psychodidae	<i>Lutzomyia</i>	0	1

No.	Classification			Population	
	Order	Family	Genus	Papaya	Banana
20.	Thysanoptera	Thripidae	<i>Thrips</i>	16	11
21.			<i>Frankliniella</i>	4	2
22.		Phlaeothripidae	<i>Klambothrips</i>	5	12
23.	Lepidoptera	Hesperiidae	<i>Erionota</i>	0	16
24.			<i>Pelopidas</i>	10	0
25.		Erebidae	<i>Sphrageidus</i>	0	2
26.			<i>Amata</i>	2	0
27.	Ustyurtiidae	<i>Ustyurtia</i>	3	0	
28.	Blattodea	Blattellidae	<i>Blattella</i>	1	0
				689	923

The most abundant genus on cocoa farms is *Empoasca*, with 360 individuals on shaded cocoa with papaya trees and 232 individuals on shaded cocoa with banana trees. The adult *Empoasca* has yellowish-green coloration and measures 2.33–2.65 mm in length (Indriati & Soeshanty, 2015). *Empoasca* has wing shapes that resemble houses and vestigial eyes. Its legs are green and covered with hairs that resemble thorns (Bororing et al., 2021). Ecologically, *Empoasca* functions as a sap-feeding insect that can cause damage to cocoa leaves, leading to chlorosis, reduced photosynthetic capacity, and potential yield loss when populations are high. The greater abundance of this genus in papaya-shaded plots suggests that this shading system may provide more suitable habitat conditions for its development and feeding activity. According to Kusumadewa & Supatman (2018) The nymph and adult stages of *Empoasca* are found on the undersides of leaves, particularly at leaf tips. However, under forced conditions, they are also often found on the upper surface of leaves, albeit briefly. The nymphal and adult stages of *Empoasca* feed on plant leaves, and at high population densities, they can cause substantial damage. A population density of three *Empoasca* individuals per shoot can already cause damage to the shoot, which initially appears pale, then turns yellow, and finally dries out. Heavy infestations can reduce production by 50%.

Fruit flies from the Tephritidae family, *Bactrocera*, are found in cocoa fields shaded by papaya trees, as many as 12 individuals, and in cocoa fields shaded by banana trees, as many as 22 individuals. According to Sartika et al. (2022), Fruit flies (*Bactrocera*) are one of the main pests in horticultural plants. *Bactrocera* belongs to the Order Diptera and the family Tephritidae, which are important in the cultivation of fruit and vegetable crops. In particular, fruit flies cause damage and potentially reduce fruit production. Fruit flies usually attack and lay eggs on underripe fruits. The female fly perches on the target and lays eggs by inserting the ovipositor into the fruit. Freshly pierced fruit is difficult to recognize because it has only small black dots. At a severe attack rate, fruit flies result in the fall of the fruit before it reaches the desired ripeness. The presence of this insect in cocoa fields is attributable to *Bactrocera*'s preference for the fruits of shade plants, namely papaya and banana. According to the results of the research of Alyaminy et al. (2024) The fruit fly *Bactrocera* (Diptera: Tephritidae) is recognized as a destructive and persistent fruit fly pest. *Bactrocera* infects more than 250 species of host plants, including mango, banana, guava, orange, papaya, peach, grape, pomegranate, lychee, and longan.

Diversity of Genera in Cocoa Plantations

The results showed that the genus diversity index was 1.75 in cocoa plantations shaded by papaya trees and 2.09 in cocoa plantations shaded by banana trees. Because both values fall within the range of 1 to 3, the genus diversity in both plantation types can be classified as moderate. These results indicate that pest insect genus diversity was higher in cocoa plantations shaded by banana trees than in those shaded by papaya trees.

This difference is likely related to the availability of food resources for pest insects. Cocoa plantations shaded by banana trees appeared to provide more food resources than those shaded by papaya trees, which may have contributed to the higher diversity observed. This interpretation is supported by Putra et al. (2017), who stated that greater food availability is an important factor contributing to high insect diversity, as insects utilize available plant-based resources as a source of energy. In addition, the higher diversity under banana shade may also be associated with differences in canopy structure and microhabitat conditions. Banana plants form a denser canopy that creates more heterogeneous microclimatic conditions, including variation in light intensity, humidity, and shelter, which can support a wider range of insect taxa. In contrast, the more open canopy of papaya creates relatively homogeneous environmental conditions, potentially limiting niche differentiation. The genus diversity index (H') values in cocoa plantations are presented in Figure 1.

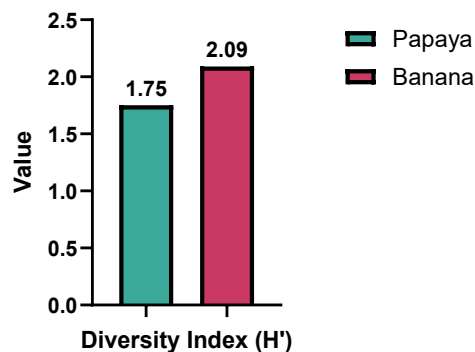


Figure 1. Diversity index of genera in cocoa land

Evenness of Genera in Cocoa Plantations

The results showed that the genus evenness index on cocoa plantations shaded by papaya trees was 0.58, which falls within the moderate evenness category and indicates a relatively unstable community. In contrast, the genus evenness index on cocoa plantations shaded by banana trees was 0.68, which is categorized as high evenness. This difference may be attributed to the greater availability of food resources in cocoa plantations shaded by banana trees compared with those shaded by papaya trees. Palealu et al. (2022) stated that high evenness index values in a research area are influenced by environmental factors within each ecosystem, food availability, and vegetation that supports insect life.

Banana trees have denser canopies than papaya trees, allowing insects to access food resources and suitable breeding sites more easily. This is consistent with Rahayuningsih et al. (2012), who stated that a habitat is not only a place where an organism lives, but also one that provides food and functions as a site for shelter, activity, rest, reproduction, and offspring development. The higher evenness observed under banana shade is therefore likely influenced by a combination of ecological factors, including food availability and habitat structure. Banana plants form a denser canopy that creates more heterogeneous microhabitat conditions, such as variation in

light intensity, humidity, and shelter, which may support a more balanced distribution of insect populations across taxa. In contrast, the more open canopy of papaya tends to produce relatively homogeneous environmental conditions, which may limit niche differentiation. The genus evenness index (E') on cocoa plantations is presented in Figure 2.

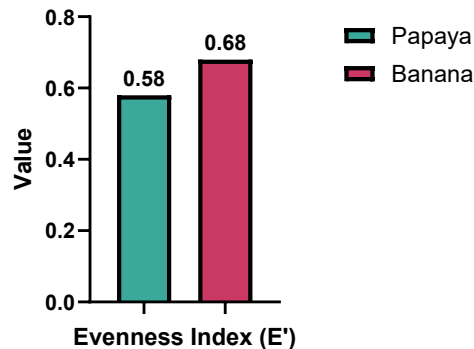


Figure 2. Evenness index of genera in cocoa land

Richness of Genera in Cocoa Plantations

The richness index values for the genus on shaded cocoa land with papaya trees and on shaded cocoa land with banana trees are 3.06 and 3.08, respectively. The richness index for these cocoa lands falls within the moderate category. The index value of pest insect richness on shaded cocoa land under banana trees is slightly higher compared to shaded cocoa land under papaya trees. The slightly higher richness observed under banana shade may be associated with differences in canopy structure and the resulting microclimatic conditions. Banana plants have broader and denser canopies, which can create more heterogeneous environmental conditions, including variations in light intensity, humidity, and temperature. Such heterogeneity may support a wider range of ecological niches, thereby allowing more insect taxa to coexist. In contrast, the more open canopy of papaya tends to produce relatively uniform environmental conditions, which may limit habitat diversity. According to Akbar et al. (2019) Canopy cover can affect the intensity of sun exposure. This condition triggers evaporation in the ecosystem, which affects insect abundance. The value of the genus Richness index (R') on cocoa land can be seen in Figure 3.

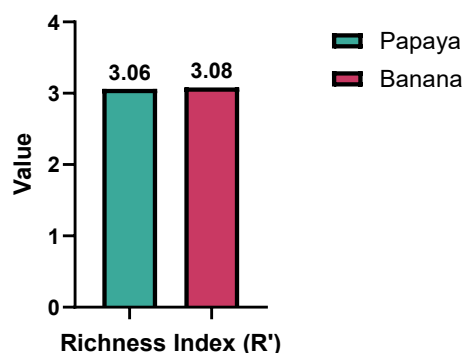


Figure 3. Richness index of genera in cocoa land

Dominance of Genera in Cocoa Plantations

The calculation results show that the dominance index for shaded cocoa land with papaya trees is 0.32, and for shaded cocoa land with banana trees is 0.18. The dominance index values for both lands are below 0.5, indicating that the dominance

index falls within the low category. The dominance index of the path on cocoa land under papaya trees is higher than on cocoa land under banana trees. The relatively higher dominance under papaya shade may be associated with more homogeneous environmental conditions resulting from its more open canopy structure, which can limit niche diversity and favor certain adaptable taxa. In contrast, the denser canopy of banana trees creates more heterogeneous microhabitat conditions, supporting a wider range of taxa and reducing the likelihood of dominance by a few genera. According to Taradipha et al. (2018) Not all insects can live with low resource availability. Limited availability of resources leads to competition in utilizing resources, the formation of new habitats, the loss of native species, and differences in insect composition, with more adaptable species being more likely to survive. The value of the genus dominance index (C') on cocoa land can be seen in Figure 4.

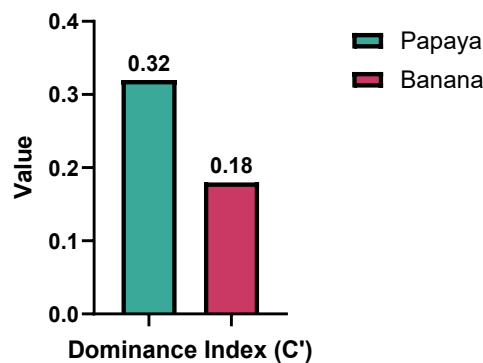


Figure 4. Dominance index of genera in cocoa land

Similarity of Pest Insect Genera in Cocoa Plantations Under Papaya Trees and Cocoa Plantations Under Banana Trees

Several pest insect genera were shared between cocoa plantations shaded by papaya and banana trees, although some genera were found exclusively in one of the systems. The occurrence of genera such as *Liriomyza*, *Bactrocera*, *Aphis*, *Empoasca*, and *Thrips* in both sites reflects their polyphagous nature, which enables them to utilize a wide range of host plants and persist under varying environmental conditions. For instance, *Liriomyza* are known to attack multiple plant families (Shahabuddin et al., 2013), *Bactrocera* are highly polyphagous and economically important pests of fruits and vegetables (Yudistira et al., 2020), *Aphis* function as vectors of plant viruses (Iqbal et al., 2023), *Empoasca* exploit diverse host plants including cocoa (Purwatiningsih et al., 2023), and *Thrips* are widely recognized as polyphagous pests across agricultural systems (Ngilamele & Pinaria, 2020). Despite this similarity, differences in community structure between the two shading systems suggest that shade tree characteristics influence not only resource availability but also microclimatic conditions and habitat complexity.

These differences are reflected in the diversity indices, where higher diversity (H') is generally associated with higher evenness (E') and lower dominance (C'), indicating a more balanced community structure. In more structurally complex environments, such as banana-shaded systems, increased habitat heterogeneity can support a more even distribution of individuals among genera, whereas simpler canopy structures, such as those under papaya shade, may favor the dominance of certain taxa. This pattern is consistent with previous findings in cocoa agroforestry and other shaded agricultural systems, which show that increased shade complexity enhances insect diversity and promotes more stable ecological interactions. Representative images of

insect pests found in cocoa fields shaded by papaya trees and banana trees are presented in Figure 5.

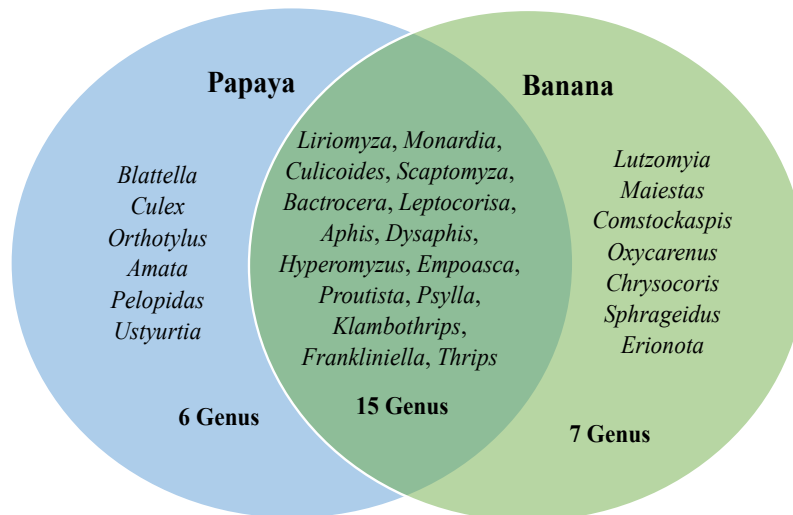


Figure 5. Comparison of pest insect genera on cocoa land

CONCLUSION

The number of pest insect genera recorded in cocoa plantations shaded by papaya and banana trees was 21 and 22, respectively. Although this difference is small, banana-shaded systems showed higher diversity, evenness, and abundance, likely due to their denser canopy structure, which creates more heterogeneous microhabitats that support a wider range of insect taxa and promote aggregation. In contrast, the more open canopy of papaya results in more homogeneous conditions and a more uniform distribution of pests. These findings have practical implications for pest management, where banana-shaded systems require hotspot-based monitoring and targeted (spot) treatments, while papaya-shaded systems are better managed using systematic (grid-based) sampling and uniform control measures. Future studies should incorporate seasonal monitoring and continuous microclimate measurements to better understand pest population dynamics.

RECOMMENDATION

Future studies are recommended to include seasonal observations and continuous microclimate measurements, such as temperature, humidity, light intensity, and canopy density, to better explain pest insect population dynamics under different shade tree systems. Further research should also evaluate the role of shade trees as alternative host plants or refuges for pest insects to support more precise and ecologically based pest management strategies in cocoa plantations.

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