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Parasitoid hymenoptera community in cayenne pepper (*Capsicum frutescens* L.) and peanut (*Arachis hypogaea* L.) intercropping systems

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Abstract

Intercropping systems, an ecological engineering strategy, have the potential to increase the abundance of parasitoid Hymenoptera in agroecosystems. This study aimed to analyze the diversity, relative abundance, and composition of parasitoid Hymenoptera in different intercropping systems of cayenne pepper and peanuts, based on differences in the peanut plant composition. The study was conducted using a randomized block design (RBD) with four treatments and five replicates. Sampling was performed using yellow pan traps and pitfall traps. Data were analyzed using the Shannon-Wiener diversity index (H'), evenness (E), dominance (D), and species richness (R). The results show that the parasitoid Hymenoptera community consisted of 79 individuals belonging to 12 families and 29 morphospecies. The highest relative abundance was found in *Trichopria* spp. (24 individuals; 30.37%). The Diapriidae family was the most abundant, with 33 individuals (41.77%). The TS2 treatment (ratio 1:3) resulted in the highest diversity (H' = 2.36) and species richness (R = 4.84). However, ANOVA indicated that neither parasitoid abundance ($F_{3,12} = 2.599$; $P > 0.05$) nor morphospecies richness ($F_{3,12} = 3.207$; $P > 0.05$) differed significantly among treatments. These findings suggest that cayenne pepper–peanut intercropping may support parasitoid communities, although the effects of different peanut proportions require further investigation under broader ecological conditions.

Introduction

The order Hymenoptera is one of the four largest orders of insects and contains the greatest number of families compared to other orders. These families are divided into two suborders, the Apocrita (ants, bees, wasps) and the Symphyta (sawflies) (Forbes et al., 2018), and comprise 132 families, 9,108 genera, and 155,517 identified species (Aguiar et al., 2013). Members of the suborder Apocrita play an important role as beneficial insects, with approximately 80% of Hymenoptera functioning as parasitoids (Rasplus et al., 2010). The crucial role of parasitoids in agroecosystems is their ability to naturally keep agricultural pest populations below the economic threshold of harm (Taye et al., 2017; Muliani & Srimurni, 2022). The use of parasitoids as biological control agents is increasingly applied in various parts of the world (Kenis et al., 2019; Pinto et al., 2020) because they are considered effective in parasitizing various developmental stages of the host, such as eggs, larvae, larval pupae, pupae (Burke & Sharanowski, 2024; Mursyidin et al., 2025; Aprilia & Rizali, 2026) and imago (Pinto et al., 2020), so their existence in the agroecosystem is of great importance (Ikhsan et al., 2020). Parasitoids exhibit high host specificity and depend on the presence of their host to complete their life cycle by laying their eggs inside the host's body (endoparasitoid) or outside

(ectoparasitoid) and eventually killing their host (Kalshoven, 1981; Fei et al., 2023; Polaszek & Vilhemsen, 2023).

The diversity and abundance of parasitoids in agroecosystems are frequently influenced by homogeneous monocultures and the common use of synthetic insecticides to achieve high yields (Nugraha et al., 2014). However, the improper use of chemicals with regard to dosage and application technique can promote pest resistance and re-emergence (Boaventura et al., 2020), reduce populations of natural enemies, including parasitoids (Otim et al., 2024; Verdadero et al., 2025), and damage the environment (Togola et al., 2018). Therefore, it is necessary to promote more environmentally friendly and sustainable farming methods in agriculture.

The role and effectiveness of parasitoids in agroecosystems can be enhanced by manipulating natural habitats in agricultural landscapes using ecological engineering strategies (Pilianto et al., 2021; Sulthoni et al., 2023). One such strategy is the implementation of intercropping systems with companion crops (Asmoro et al., 2021; Karabo et al., 2019). This increases biodiversity and creates more diverse and ideal habitats for parasitoids, providing them with protection, enabling them to search for alternative hosts (Fuller et al., 2018; Lizmah et al., 2019), and offering food sources in the form of nectar and pollen for adult parasitoids (Aldinas et al., 2023; Marco et al., 2026). The presence of flowering plants has been shown to increase the effectiveness of parasitoids by providing them with additional energy, thereby increasing their lifespan, fertility, and host parasitism capacity (Fataar et al., 2019; Usman et al., 2025). Compared to monocultures, intercropping allows for greater structural and functional diversity, which can attract and maintain parasitoid populations on agricultural land (Sahari et al., 2020; Prabowo et al., 2021; Wagiyana et al., 2025).

Several studies have shown that intercropping can increase the diversity and abundance of parasitoid hymenopterans. Januarisya et al. (2023) reported that parasitoid diversity and abundance were significantly higher in polyculture systems of cayenne pepper with peanut cultivation than in monoculture systems. Sataral et al. (2023) found that mung beans, used as a barrier crop in cayenne pepper cultivation, can attract beneficial insects, including parasitoids, and increase their populations by providing suitable microhabitats. Parahdiba et al. (2023) also reported that the composition of parasitoid hymenopterans in chili pepper cultivation with intercropping of spring onions and long beans was higher and more diverse than in chili pepper monoculture. Another study on parasitoid diversity in red chili peppers in intercropping with basil (*Ocimum basilicum*) and marigolds (*Tagetes erecta*) showed that parasitoid diversity and abundance were significantly higher in intercropping than in monocultures (Souza et al., 2019). The use of parasitoids as biological control agents within integrated pest management (IPM) programs is more environmentally friendly and sustainable, thus reducing the use of synthetic insecticides (Pinto et al., 2020).

Although several studies have demonstrated that intercropping can enhance parasitoid abundance and diversity, most investigations have compared monoculture and intercropping systems without evaluating how different proportions of companion plants influence parasitoids community structure. In agroecosystems, peanut (*Arachis hypogaea*) is potential companion crop because it increases vegetation diversity, optimizing photosynthetic efficiency, improving soil microecology (Li et al., 2022; Wang et al., 2025), and may support natural enemies by improving habitat complexity (Latha et al., 2022). However, different peanut proportions can alter resource availability, host distribution, and microclimatic conditions, which may influence parasitoid communities (Wang et al., 2024).

Information regarding the effect of varying peanut densities within cayenne pepper–peanut intercropping systems remains limited, particularly under tropical dryland conditions. Understanding these responses is essential for designing ecological engineering strategies that maximize natural enemy conservation and biological control services. Therefore, this study aims to evaluate the effects of different peanut proportions in cayenne pepper–peanut intercropping systems on the diversity, relative abundance, and composition of parasitoid Hymenoptera under tropical dryland conditions.

Materials and methods

Time and place

The study was conducted from March to August 2025 in the village of Dasan Geres, Kuripan District, West Lombok Regency, West Nusa Tenggara, at coordinates 8°39'28.8"S, 116°09'54"E and an altitude of 32 meters above sea level. The identification of the parasitoid Hymenoptera was carried out in the Plant Protection Laboratory of the Faculty of Agriculture at Mataram University.

Materials and instruments

The materials used in this study included cayenne pepper (*Capsicum frutescens* L.) seeds, peanut (*Arachis hypogaea* L.) seeds, cattle manure, dolomite, urea, SP-36 fertilizer, KCl fertilizer, NPK Grower fertilizer, NPK Pak Tani fertilizer, Cal-Ha fertilizer, and 70% alcohol for specimen preservation. The instruments used consisted of seedling trays, yellow pan trap, pitfall trap, Eppendorf tube 5 mL, forceps, fine brushes, a soil pH meter, a digital thermometer, labeling materials, a stereo microscope LEICA M80, and digital camera for field documentation and specimen identification.

Research implementation

The method used in this study was descriptive-quantitative. Sampling took place in a field where cayenne peppers were grown in intercropping with peanuts. A randomized block design (RBD) with four treatments and five replicates was used, resulting in a total of 20 observation plots. The treatments used in this study are shown in Table 1.

Table 1. Codes and treatments for the intercropping of cayenne pepper and peanuts

Code	Treatment
TS0	Cayenne pepper monoculture without peanuts
TS1	Intercropping cultivation of cayenne pepper and peanuts in a ratio of 1:2 (18 cayenne peppers: 36 peanuts)
TS2	Intercropping cultivation of cayenne pepper and peanuts in a ratio of 1:3 (18 cayenne peppers: 54 peanuts)
TS3	Intercropping cultivation of cayenne pepper and peanuts in a ratio of 1:4 (18 cayenne peppers: 72 peanuts)

The experimental field was prepared by constructing plots measuring 3 m × 1 m, with 50 cm spacing between plots. Soil pH was measured prior to planting, and dolomite was applied when necessary to improve soil conditions. Basal fertilization consisted of cattle manure (1 kg plot^{-1}), urea (80 g plot^{-1}), SP-36 (60 g plot^{-1}), and KCl (60 g plot^{-1}), which were incorporated into the soil before planting. Cayenne pepper seeds were sown in seedling trays containing a mixture of soil, compost, and manure (1:1:1, v/v/v). Seedlings were maintained under partial shade and watered twice daily. Four-week-old seedlings with 3–4 true leaves were transplanted into the field at a spacing of 60 cm × 50 cm, with one seedling per planting hole. Peanut seeds were planted three weeks after chili transplantation according to the intercropping treatments.

Field maintenance included daily irrigation, replacement of dead seedlings, when necessary, weekly hand weeding, and pruning of axillary shoots between 20 and 45 days after transplanting. Supplemental fertilization was applied at 3 and 6 weeks after transplanting using NPK fertilizers according to local cultivation recommendations. No insecticides were applied throughout the experimental period to allow the natural occurrence and colonization of parasitoids insects.

Observation and sampling

The observation and sampling of the parasitoids was carried out using two types of traps: yellow pan traps and pitfall traps. Yellow pan traps are a type of yellow trap measuring 14 × 14 cm in diameter and 17 cm in height, designed to attract parasitoids sensitive to the color yellow. Yellow pan traps are filled with 500 mL water containing 2 mL detergent solution to one-third of their total volume (Buchori et al., 2023) and installed according to the height of the cayenne pepper plants. A total of two yellow pan traps were placed among the cayenne pepper and peanut plants for each treatment. Pitfall traps are used to capture parasitoids that fly around and fall into the trap. Pitfall traps are buried in the soil and filled with 250 mL water containing 2 mL detergent solution. A total of two pitfall traps were placed among the cayenne pepper and peanut plants for each treatment. Each type of trap is set up around 7:00 a.m. (GMT+7) and left in place for 24 hours.

Environmental observations were conducted concurrently with parasitoid sampling. Air temperature was measured in each experimental plot using a digital thermometer at canopy level between 08:00 and 09:00 a.m. (GMT+7) during each sampling event. Observations and sampling were carried out weekly when the plants were four weeks old after transplanting. Further observations were made four to eight weeks

after transplanting. Captured parasitoid samples were collected and transferred to Eppendorf tubes measuring 5 mL of a 70% alcohol solution for sorting and identification in the laboratory.

Parasitoid identification

Parasitoid specimens collected in the field were counted and grouped based on morphological similarity. Parasitoid identification was performed by observing morphological characteristics such as wing type and venation, legs, antenna type, thorax, and other features using a stereo microscope LEICA M80 and documented with a digital camera. Identification was carried out down to the family or morphospecies level and, where possible, to the species level. The identification keys used were taken from the following books: Hymenoptera of the World: An Identification Guide to Families (Goulet and Huber, 1993), The Pests of Crops in Indonesia (Kalshoven, 1981), the journals: A Review of Aphid Parasitoids, with an Identification Key to the Genera of Economic Importance (Ferrer-Suay et al., 2025), Description of the Diapriidae Family (Insecta: Hymenoptera) (Marchiori, 2022), and the websites: BugGuide.Net and iNaturalist.

Data analysis

The identified parasitoids were descriptively analyzed using the Shannon-Wiener diversity index (Magurran, 1998), the Pielou's evenness index (Krebs, 2000), the Simpson dominance index (Odum, 1998), and the Margalef's morphospecies richness index (Santosa, 1995). These indices were calculated using Microsoft Excel 2019.

The species diversity index was measured using the Shannon-Wiener diversity index (Magurran, 1998) as follows:

$$H' = -\sum p_i \, ln \, p_i \; ; \; pi = \frac{n_i}{N}$$

H' : Shannon-Wiener diversity index;
pi : the proportion of the i^{th} species individual in the community;
ni : number of individuals of the i^{th} species;
N : total number of individuals;
ln : natural logarithm,

with the categories high: H' ≥ 3; moderate: H' = 1 < H' ≤ 3; and low: 0 < H' ≤ 1.

Evenness index measurement was carried out using the Pielou's evenness index (Krebs, 2000) as follows:

$$E = \frac{H'}{ln \, (S)}$$

E : Pielou's evenness index;
H' : Shannon-Wiener diversity index;
S : total number of species;
ln : natural logarithm,

with the categories high: E > 0.60; moderate: 0.40 ≤ E ≤ 0.60; and low: E < 0.40.

The species dominance index was measured using the Simpson dominance index (Odum, 1998) as follows:

$$D = \sum \left[\frac{n_i}{N}\right]^2$$

D : Simpson dominance index;
ni : number of individuals of the i^{th} species;
N : total number of individuals,

with the categories high: 0.75–1; moderate: 0.5–0.75; and low: 0–0.5.

The morphospecies richness index was measured using Margalef's (Santosa, 1995) as follows:

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

R : Margalef's morphospecies richness index;
S : total number of species;
N : total number of individuals;
ln : natural logarithm,

with the categories high: R > 4; moderate: 2.5 < R < 4; and low: R < 2.5.

The relative abundance of each parasitoid species found was calculated using the formula by Molina-Ochoa et al. (2001) as follows:

$$RA = \frac{Ni}{Nt} \times 100\%$$

RA : relative abundance;
Ni : total number of individuals of the i^{th} species;
Nt : total number of individuals.

The effect of intercropping treatments on parasitoid abundance and morphospecies richness was analyzed using one-way analysis of variance (ANOVA) based on a randomized block design (RBD). Statistical significance was determined at $P < 0.05$. All statistical analyses were performed using Minitab 17.

Results and discussion

1. Diversity and relative abundance of parasitoid Hymenoptera

This study identified 79 parasitoid hymenopterans from 12 families and 29 morphospecies. These families include *Diapriidae, Braconidae, Scelionidae, Figitidae, Eulophidae, Pteromalidae, Encyrtidae, Ceraphronidae, Aphelinidae, Aphidiidae, Bethylidae, and Torymidae* (Table 2, Figure 2). The *Diapriidae* family was the most abundant, with 33 individuals and 6 morphospecies, while *Encyrtidae, Aphidiidae, Bethylidae*, and *Torymidae* were the least abundant, with one individual and one morphospecies each. The highest number of individuals and morphospecies was found in the TS2 treatment with 41 individuals and 17 morphospecies, respectively, followed by TS1 with 21 individuals and 8 morphospecies, TS3 with 9 individuals and 6 morphospecies, and the lowest number in TS0 with 8 individuals and 2 morphospecies. The parasitoid with the highest relative abundance was *Trichopria* spp. (24 individuals; 30.37%), while other morphospecies with relatively high relative abundance included *Alloxysta* sp. (6 individuals; 7.60%), *Ceraphron* sp. (5 individuals; 6.32%), and *Diapriidae* sp.2 (4 individuals; 5.06%).

Although the TS2 treatment recorded the highest number of parasitoids with 41 individuals and 17 morphospecies, the one-way analysis of variance (ANOVA) indicated that the intercropping treatments did not significantly affect either parasitoid abundance ($F_{3,12} = 2.599$; $P > 0.05$) or morphospecies richness ($F_{3,12} = 3.207$; $P > 0.05$). These results indicate that variations in peanut proportion within the intercropping system were not sufficient to produce statistically detectable changes in parasitoid abundance and richness under the conditions of this study.

The results of this study indicate that the intercropping system of cayenne pepper and peanuts generally exhibits higher diversity and relative abundance of parasitoid hymenopterans than the cayenne pepper monoculture. This is attributed to differences in the vegetation structure of the two cropping systems, which may have different ecological effects on the structure of the parasitoid hymenopteran communities. According to Sataral et al. (2023), the difference in insect abundance between cayenne pepper monoculture and intercropping is caused by differences in plant characteristics of both cultivation patterns. Monoculture systems with vegetation limited to a single plant species (high homogeneity) generally create microhabitat conditions that are less favorable to the occurrence of natural enemies. This leads to accelerated pest development due to a lack of natural control mechanisms (Nugraha et al., 2014).

In contrast, intercropping systems with greater vegetation diversity (high heterogeneity) can increase the occurrence and role of natural enemies, including parasitoid hymenopterans (Supriyadi & Bashir, 2024). This is due to the presence of additional resources such as nectar, pollen, shelter, and more complex microhabitats (Fuller et al., 2018; Shrestha et al., 2019; Aldinas et al., 2023). Lizmah et al. (2018) also showed

that agricultural landscapes with more complex vegetation structures can exhibit higher biodiversity than simpler agricultural landscapes. Furthermore, it has been shown that the manipulation of natural habitats increases the occurrence of beneficial insects in agroecosystems (Prabowo et al., 2021; Soujanya et al., 2024), including predators and parasitoids (Rahardjo et al., 2018; Marco et al., 2026). Studies by Aprilia & Rizali (2026) revealed that under complex agricultural landscape conditions, up to eight families and 21 morphospecies of parasitoid hymenopterans occur, parasitizing various developmental stages of pests such as eggs, larvae, egg larvae, and pupae.

Table 2. Diversity and relative abundance of parasitoid hymenopterans in the cayenne pepper and peanut intercropping agroecosystem

Family	Morphospecies	Treatment				Abundance	RA
		TS0	TS1	TS2	TS3		
Diapriidae	*Trichopria anastrephae*		1			1	1.26
	Trichopria spp.	7	8	9		24	30.37
	Diapriidae sp.1		2			2	2.53
	Diapriidae sp.2			4		4	5.06
	Diapriidae sp.3				1	1	1.26
	Diapriidae sp.4			1		1	1.26
Braconidae	*Chelonus* sp.1		1			1	1.26
	Chelonus sp.2			1		1	1.26
	Braconidae sp.	1				1	1.26
Scelionidae	*Scelio* sp.1			3		3	3.80
	Scelio sp.2				1	1	1.26
	Calliscelio sp.		1			1	1.26
	Trimorus sp.			3		3	3.80
	Scelionidae sp.			1	2	3	3.80
Figitidae	*Alloxysta* sp.		5	1		6	7.60
	Figitidae sp.1			2		2	2.53
	Figitidae sp.2				3	3	3.80
Eulophidae	*Tetrastichus* sp.1			2		2	2.53
	Tetrastichus sp.2		2			2	2.53
	Tetrastichus sp.3			1		1	1.26
	Elasmus sp.			2		2	2.53
Pteromalidae	*Pteromalidae* sp.			3		3	3.80
Encyrtidae	*Encyrtidae* sp.			1		1	1.26
Ceraphronidae	*Ceraphron* sp.			5		5	6.32
Aphelinidae	*Aphelinus mali*		1			1	1.26
	Encarsia sp.			1		1	1.26
Aphidiidae	*Aphidius* sp.				1	1	1.26
Bethylidae	*Bethylidae* sp.				1	1	1.26
Torymidae	*Torymidae* sp.			1		1	1.26
Total of morphospecies		2	8	17	6	29	
Total of individuals		8	21	41	9	79	

Note: TS0: Cayenne pepper monoculture; TS1: Cayenne pepper-peanut intercropping (1:2); TS2: Cayenne pepper-peanut intercropping (1:3); TS3: Cayenne pepper-peanut intercropping (1:4); RA: Relative Abundance (%)

2. Composition of parasitoid Hymenoptera

The composition of the parasitoid Hymenoptera family shows that the *Diapriidae* have the highest proportion of individuals at 41.77%, followed by the *Figitidae* and *Scelionidae* (both at 13.92%), the *Eulophidae* (8.86%), and the *Ceraphronidae* (6.32%). Other families, however, showed significantly lower numbers of individuals, ranging from 1.26% to 3.80% (Figure 1). This study identifies different groups of parasitoid Hymenoptera based on the host stage being parasitized, including egg parasitoids, larvae, pupae, and some

are considered hyperparasitoids. Several families are known to parasitize the egg stage: *Scelionidae, Encyrtidae,* and *Aphelinidae*; the larval stage: *Diapriidae, Figitidae, Eulophidae, Braconidae*, and *Bethylidae*; and the pupal stage: *Ceraphronidae* and *Pteromalidae*. The families suspected of acting as hyperparasitoids are *Eulophidae*, *Ceraphronidae*, and *Figitidae*.

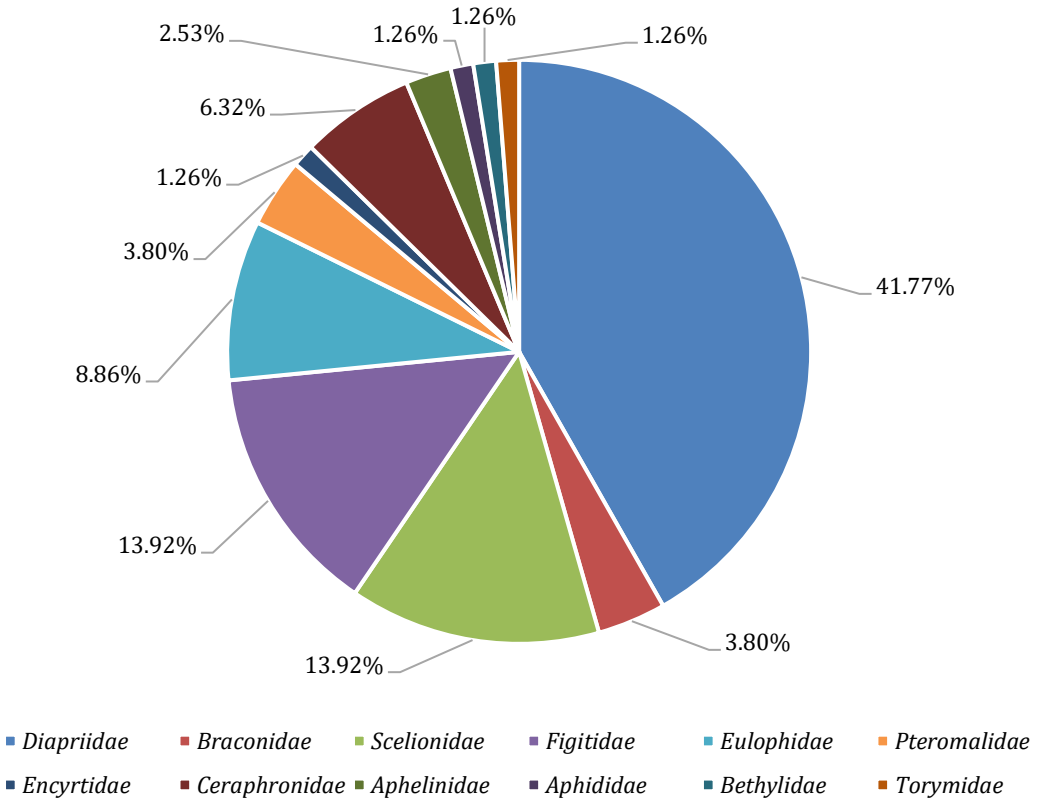

Figure 1. Percentage composition of the abundance of the parasitoid Hymenoptera family in various intercropping cultivation of cayenne pepper and peanut

The *Diapriidae* are a globally distributed family of parasitoids with 2,080 described species in 194 genera. They primarily parasitize Diptera (*Brachycera* and *Cyclorrhapha*), some species parasitize beetle larvae (*Staphylinidae* and *Scarabidae*), and others are associated with ants (*Formicidae*) (Marchiori et al., 2022). The *Figitidae* are parasitoids that parasitize the larval stages of other insects, particularly Diptera (*Cyclorrhapha*), with the exception of the subfamily *Charipinae*, whose members are hyperparasitoids of Hymenoptera (Ferrer-Suay et al., 2023). The *Scelionidae* are generally known as egg parasitoids with a broad host range and parasitize, among others, the eggs of pest insects of the orders Lepidoptera, Hemiptera, and Orthoptera (Kalshoven, 1981). For example, the parasitoid *Telenomus remus* is considered the primary parasitoid of the egg stage of *Spodoptera frugiperda* in maize crops (Abang et al., 2021; Herlinda et al., 2023; Mursyidin et al., 2024). The *Eulophidae* comprises 324 genera and 5,300 species distributed among four subfamilies. Most *Eulophidae* are primary parasitoids, infecting the larval stage of their hosts, particularly flies (Diptera) and butterflies (Lepidoptera); some function as hyperparasitoids (Noyes, 2019). The *Ceraphronidae* are the primary parasitoids or hyperparasitoids of various insects in the orders Lepidoptera, Hemiptera, and Hymenoptera (Micheal, 2015). The *Braconidae* are a very large family of parasitoid hymenopterans with around 22,000 identified species from 1,250 genera (Noyes, 2019). Almost all *Braconidae* function as ectoparasitoids and endoparasitoids, many of which parasitize the larvae or pupae/nymphs of their hosts from the orders Coleoptera, Hemiptera, and Lepidoptera (Loni et al., 2016; Oliveira et al., 2017; Kiesmuller et al., 2026).

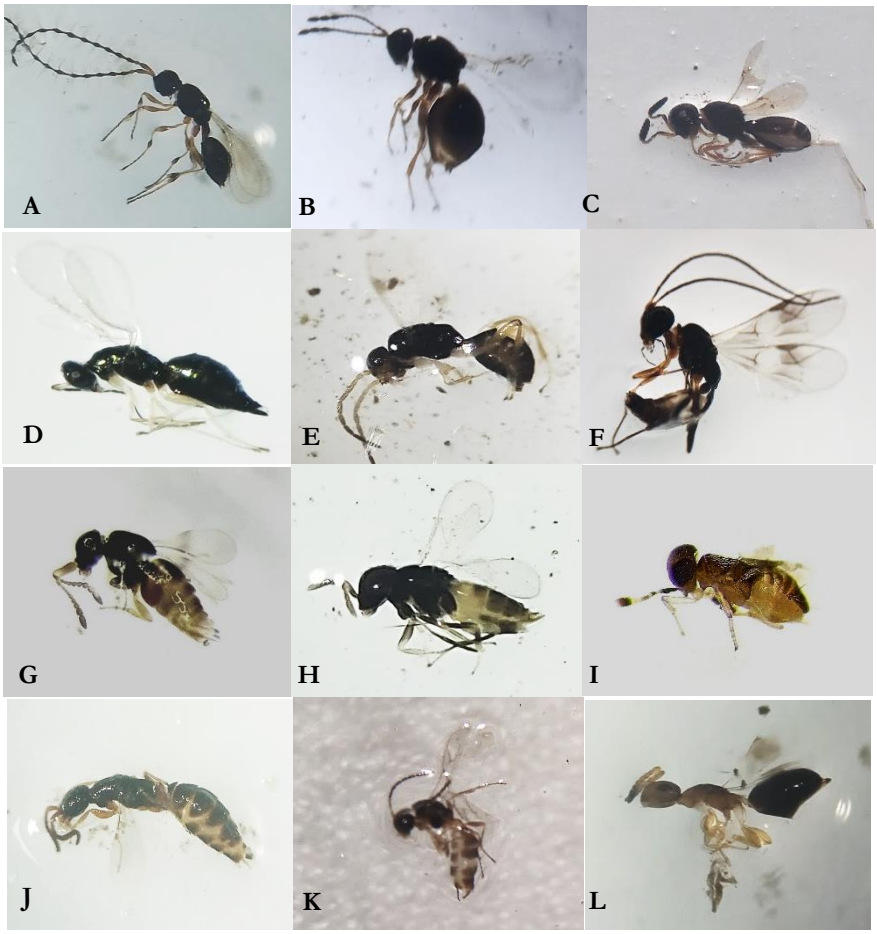

Figure 2. Parasitoid Hymenoptera families in the intercropping agroecosystem of cayenne pepper and peanuts. A: *Diapriidae*; B: *Figitidae*; C: *Scelionidae*; D: *Eulophidae*; E: *Ceraphronidae*; F: *Braconidae*; G: *Pteromalidae*; H: *Aphelinidae*; I: *Encyrtidae*; J: *Bethylidae*; K: *Aphidiidae*; L: *Torymidae*.

The *Pteromalidae* are a group of small (approximately 3 mm) parasitoids and constitute one of the largest families within the species-rich superfamily *Chalcidoidea*. Most species develop as solitary or swarm parasitoids, parasitizing the developmental stages of insect hosts, including larvae and pupae of the orders Diptera, Coleoptera, Hymenoptera, and Lepidoptera (Kalshoven, 1981; Boucek & Rasplus, 1991). The *Aphelinidae* are the major parasitoids of the Hemiptera (*Aleyrodoidea*, *Aphidoidea*, *Coccoidea*, and *Psylloidea*), representing significant agricultural pests (Dong et al., 2024). The *Encyrtidae* comprise about 460 genera and 3,735 identified species, divided into two subfamilies: *Encyrtinae* and *Tetracnemindae*. These play a crucial role in controlling mealybugs and other aphids (Noyes, 2019). The *Bethylidae* are a globally distributed family of parasitoids whose members primarily act as endoparasitoids and ectoparasitoids of beetle larvae, pupae, and adults (Coleoptera)—especially weevils (*Curculionidae*) and longhorn beetles (*Cerambycidae*) (Karimi et al., 2017; Honsberger et al., 2024). The *Aphidiidae* are a family of ichneumonoid wasps that specifically parasitize aphids as solitary endoparasitoids (Al-Hussainawy et al., 2019; Maharani et al., 2020). The *Torymidae* are parasitoids that generally parasitize insects that cause plant galls, such as those from the order Diptera (*Cecidomyiidae*) (Lotfalizadeh & Mohammadi-Khoramabadi, 2015), including parasitoids associated with eucalyptus galls (Puspasari et al., 2021).

2. Diversity index (H'), evenness (E), dominance (D), and morphospecies richness (R) of parasitoid Hymenoptera

The results of the ecological index analysis of parasitoid Hymenoptera in each treatments showed significant differences. The diversity index was classified as moderate in treatments TS1, TS2, and TS3, but low in TS0 (Table 3). Treatment TS2 had the highest value at 2.36, followed by TS1 at 1.73 and TS3 at 1.53,

while the value in TS0 was 0.37. The moderate diversity index suggests that the intercropping of cayenne pepper and peanuts was relatively stable. This means that the existence of the parasitoid Hymenoptera community is favored by the existing vegetation and the more diverse plant composition compared to the cayenne pepper monoculture. Therefore, intercropping systems may contribute to pest suppression through the activity of parasitoids. According to Soujanya et al. (2024), maize-legume intercropping systems exhibit high abundance of parasitoids that can suppress the incidence of fall armyworm infestations.

Table 3. Diversity, evenness, dominance, and morphospecies richness indices of parasitoid Hymenoptera in the cayenne pepper and peanut intercropping agroecosystem

Treatment	H'	Category	E	Category	D	Category	R	Category
TS0	0.37	Low	0.54	Moderate	0.78	High	0.48	Low
TS1	1.73	Moderate	0.83	High	0.23	Low	2.30	Low
TS2	2.36	Moderate	0.63	High	0.09	Low	4.84	High
TS3	1.53	Moderate	0.85	High	0.14	Low	3.34	Moderate

Note: H': Diversity; E: Evenness; D: Dominance; R: Morphospecies richness

This result is consistent with the findings of Mursyidin et al. (2025), the moderate diversity index suggests that parasitoids in banana agroecosystems have the same chances of infecting their hosts at every developmental stage. This contrasts with cayenne pepper monocultures, which presumably offer less favorable conditions for parasitoid hymenopterans and therefore exhibit a significantly lower parasitoid count, reflected in the low diversity index. This observation is consistent with the findings of Januarisya et al. (2023), who also reported lower parasitoid hymenopteran diversity in cayenne pepper monocultures compared to intercropping.

The evenness index indicates the distribution pattern of the parasitoid Hymenoptera morphospecies. The results show that the evenness index was categorized as moderate under monoculture and high under all intercropping treatments. This indicates that the distribution of parasitoid Hymenoptera individuals among morphospecies was relatively more balanced in the intercropping system than in monoculture. The higher evenness in intercropping suggest that the presence of multiple crops created more diverse and suitable habitat conditions, allowing parasitoid morphospecies to coexist with more balanced distribution of individuals (Ikhsan et al., 2020). In contrast, the moderate evenness observed in monoculture indicates a less balanced distribution, where some morphospecies may occur in greater numbers than others. This aligns with the results of the dominance index calculation, which is relatively low in the intercropping treatment, thus confirming the absence of a dominant morphospecies. In contrast, the monoculture treatment shows high dominance due to the dominant morphospecies *Trichopria* spp. The morphospecies richness index, however, varies considerably between treatments: TS2 shows a high value, TS3 a moderate value, and TS0 and TS1 a low value.

The results of this study show that TS2 treatment with cayenne pepper and peanuts in a 1:3 ratio (18 cayenne peppers: 54 peanuts) resulted in the highest diversity and species richness compared to other treatments. Although the TS2 treatment exhibited the highest observed abundance, diversity, and morphospecies richness of parasitoid Hymenoptera, these differences were not statistically significant according to ANOVA. Therefore, the present study does not provide sufficient evidence to conclude that the 1:3 cayenne pepper–peanut ratio is superior to the other intercropping treatments. Nevertheless, the consistently higher values recorded in TS2 suggest a potential ecological tendency toward increased parasitoid occurrence under intermediate peanut densities. Such trends may be associated with greater vegetation heterogeneity, improved habitat complexity, and increased availability of alternative resources for parasitoids.

Another factor influencing the diversity and abundance of parasitoid hymenopterans is climate, particularly temperature. The optimal temperature affects the establishment, growth, and development of parasitoids in an agroecosystem (Kumari et al., 2020; Xia et al., 2025). Average temperature measurements during the study ranged from 24–33°C. This suggests that this temperature range remains ideal for parasitoid hymenopteran activity in tropical agroecosystems. According to Colombari et al. (2020), the optimal temperature for the family *Diapriidae* (*Trichopria drosophilae*) for development, reproduction, and other activities is between 20–25°C. Furthermore, the temperature tolerance of *Braconidae* ranges from 15–30°C, with an optimal temperature for reproduction of 25°C, successful parasitism occurring at 30°C, and parasitoids dying at temperatures below 15°C (Agbodzavu et al., 2020). This abiotic factor is likely closely

related to vegetation structure, as a denser canopy influences microclimate fluctuations and thus the composition of the parasitoid Hymenoptera community.

Conclusion

Intercropping of cayenne pepper with peanut supported a more diverse parasitoid Hymenoptera community than monoculture cultivation, as indicated by higher diversity and species richness indices and lower dominance values across intercropping treatments. Among the intercropping treatments, the 1:3 cayenne pepper–peanut ratio (TS2) showed the highest observed diversity and morphospecies richness. However, one-way ANOVA revealed that differences in parasitoid abundance and morphospecies richness among treatments were not statistically significant ($P > 0.05$). These findings suggest that varying peanut proportions within the intercropping system may influence parasitoid community structure, although the observed differences were insufficient to demonstrate a significant treatment effect under the conditions of this study. Further research involving larger experimental scales, longer observation periods, and additional ecological variables is recommended to better explain the role of peanut proportion in enhancing parasitoid communities and biological control services.

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