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Microclimate Modification through Water Misting Increase Natural Enemy Insect Richness in a Cocoa Agroecosystem

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Abstract: *This study aimed to analyze the influence of abiotic factors on the diversity of natural enemies in cocoa fields. The study was conducted from January to March 2025. Various traps were used, including yellow traps, light traps, pitfall traps, and visual observations. Identification showed that cocoa fields with misting applications had a higher number of natural enemies (1,052 individuals) compared without misting fields (658 individuals). The application of misting resulted in higher diversity indices (H'), richness (R'), and dominance (C'), as well as lower evenness (E') compared to untreated fields. These findings suggest that the misting system creates a more favorable microhabitat for natural enemy diversity, thus potentially strengthening the IPM approach in cocoa cultivation. Interestingly, the analysis showed that temperature had a significance value (sig) > 0.05, indicating that temperature did not show a significant correlation with the increase in the abundance of natural enemies, while humidity has a significance value (sig) < 0.05, which shows that humidity has a significant correlation, although statistically relatively small, with the increase in the abundance of natural enemies.*
***Keywords**: Diversity; natural enemies; cocoa; misting; biological control*

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INTRODUCTION

Insects are key organisms that dominate many terrestrial ecosystems. The conservation to preserve insects in an ecosystem plays an important role in increasing biodiversity, with the aim of preventing extinction and a reduction in species diversity (Windriyanti et al., 2023). Insect diversity is a bioindicator in an ecosystem (Ali et al., 2024). The use of bioindicators aims to determine the relationship between biotic and abiotic environmental conditions and numbers abundance of natural enemies (Haneda et al., 2023). The important role of insects is grouped into two categories, namely beneficial insects and harmful insects. Pest insects can cause damage to cultivated plants by eating plant tissue, laying eggs on leaves, and acting as vectors for disease transmission (Amrullah, 2019). Cocoa cultivation faces serious challenges due to attacks by the pest *Conopomorpha cramerella*, which has not been fully controlled. Hasinu et al. (2024) reported that in 2021, PBK pest attacks could reach 140.63 ha with an attack rate of 7.7%. This condition reinforces the urgency of cocoa ecosystem research, considering Indonesia's strategic position as one of the largest cocoa producing and exporting countries in the world. Indonesia's contribution to the world cocoa trade reaches around 10% per year (Ibnu, 2022).

This situation indicates that national cocoa problems are not solely technical in nature but also reflect weak ecosystem stability within cocoa cultivation systems. Therefore, an ecosystem based approach is urgently needed as a long term solution to restore productivity, enhance plant resilience, and support the sustainability of cocoa farming in Indonesia. The ecosystem approach emphasizes that insects function not only as pests but also as beneficial organisms that serve as pollinators and biological control. Pest control using natural enemies, according to (Asril et al., 2022), aims to reduce pest populations while minimizing negative impacts on the environment. The natural enemies of cocoa plant insects consist of black ants (Hasinu et al., 2024) According to Robika et al. (2020) the presence of black ants is effective in suppressing the intensity of pest attacks on cocoa plants.

The study on the diversity of natural enemy insects was conducted in cocoa cultivation plots located inside a net house. The use of net houses can creates a more stable microclimate and serve as a physical barrier against large pest insects such as moths, beetles, and fruit flies, thereby providing an alternative method to reduce pest infestations (Prabaningrum et al., 2014). The microenvironment created inside the net house through the application water misting technology, can increase the abundance of natural enemies, as the resulting higher humidity and more stable air temperatures provide more optimal habitat conditions. The stability of the microclimate not only benefits plant growth but also enhances host availability, thereby supporting the activity of natural enemy insects. According to Malbog (2020) the fine droplets produced through water misting treatment can accelerate evaporation and increase air humidity. Optimal humidity plays an important role in enhancing the activity of natural enemy insects. This condition helps maintain body fluid balance and supports physiological processes, including metabolism and reproduction, thereby contributing overall to the increased development rate and distribution of these insects within an ecosystem (Reksiana et al., 2023).

The influence of microclimate on insects can be explained through the metabolic rate theory and the thermal performance curve theory, which state that insects, as ectothermic organisms, are highly dependent on ambient temperature to regulate their metabolic rate, physiological activity, growth, and reproduction (Kingsolver, 2017). An increase in temperature up to the optimal threshold enhances the rate of biochemical reactions within the insect body, thereby accelerating larval development, increasing feeding activity, and shortening the life cycle. Conversely, extreme temperatures outside the tolerance range reduce survival rates, inhibit reproduction, and cause physiological stress (Deutsch et al., 2018) Therefore, maintaining relative humidity within the optimal range through the application of a water misting system in a net house has the potential to create a microclimate that supports insect survival and enhances the effectiveness of natural enemies in pest control.

Abundance of natural enemies within an ecosystem are dynamic and fluctuate over time. Populations can increase or decrease depending on environmental conditions. According to Ali et al. (2024) fluctuations in insects diversity can be influenced by climatic conditions, food availability, and interactions with other species such as predators and parasitoids. Changes in environmental conditions affect insect abundance within an ecosystem, indicating that ecosystems are always in a state of dynamic balance. A high diversity of insect species demonstrates that the ecosystem is in a stable condition. This level of diversity is highly important for supporting the stability and overall functioning of ecosystems (Alrazik et al., 2017). Therefore, this study aims to enhance the diversity of natural enemy insects by providing favorable environmental conditions, thereby contributing to the control of major pests in cocoa field and maintaining ecosystem balance in a sustainable manner.

METHOD

Time and Location of Research

This research was conducted from January 2025 - March 2025 on two cocoa fields with misting treatments, and without misting treatments. The research was conducted at the cocoa plantation of PT. Mondelez International, located in Pasuruan, East Java.

Research Site Selection and Insect Data Collection

The cacao field inside the net house, with misting and non-misting treatments, measured 28 m × 33 m and contained 146 cacao plants aged three to four years. Monitoring the Abundance of natural enemies was carried out through visual observations and the use of traps. Visual observations were conducted three times a day, in the morning (05:30–08:00 WIB), at midday (12:00–13:30 WIB), and in the afternoon (15:00–16:30 WIB), allowing insect activity to be monitored throughout the day. To support these observations, 1 light trap, 9 yellow traps, and 9 pitfall traps were installed in the cacao field under both misting and non-misting treatments. The traps were placed in five plots within the cacao field using a diagonal pattern to minimize bias caused by microenvironmental factors. The distance between traps was arranged at approximately 2 m (Figure 1).

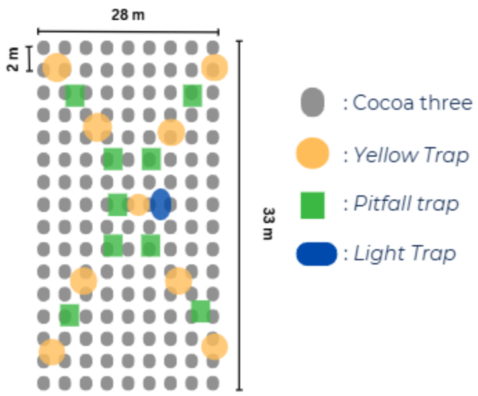

Figure 1. Trap installation layout

Abiotic Factor Measurement

Abiotic factors such as temperature and humidity were measured using an HTC-2 digital thermohygrometer. Observations were carried out by placing the device on both cocoa plots in a safe location protected from rain. Temperature and humidity were recorded twice a week over a two month period. The data obtained were analyzed using simple linear regression with IBM SPSS 26 software.The purpose of conducting the simple regression analysis was to estimate or determine the values generated from the dependent variable (Bagaswara & Astuti, 2025).

Morphological Identification and Data Analysis

Insect identification was conducted at the genus level using the book The Insects: an Outline of Entomology (Gullan, 2014) and iNaturalist software (Unger *et al*., 2021). Data on the population of natural enemy insects were analyzed quantitatively using the Shannon-Wiener diversity index (H'), the evenness index (E'), and the dominance index (C'). For the Shannon-Wiener index (H') calculation method, use the For the Shannon-Wienner (H') index calculation method, use the formula (Thifany *et al*., 2020).

$$H = -\sum\left(\frac{ni}{N}\right)\left(\mathrm{In}\,\frac{ni}{N}\right)$$

Keterangan:

H' : Diversity index
ni : The number of individuals of each type
ln : Natural logarithm
N : The total number of all individuals

The Evenness Index is calculated by the following formula (Wijayanto et al., 2022)

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

E : Evenness index
H' : Diversity of types
ln : Natural logarithm
N : Number of types

The Species Richness Index is calculated using the following formula (Wijayanto et al., 2022)

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

R : Species Richness Index
S : Total number of species observed.
ln : Natural logarithm.
N : The Total number of individuals observed.

The dominance index is calculated using the Simpson dominance index as follows (Thifany et al., 2020)

$$C = \sum (\frac{ni}{N})^2$$

C : Simpson dominance index
ni : Total number of individuals of each species
N : The total number of individuals of all species

RESULTS AND DISCUSSION

Insect Type, Population, and Composition

Observations conducted at the cocoa plantation of PT. Mondelez International, Pasuruan, East Java, recorded a total of 1,053 individuals of natural enemy insects in misting treatment and 658 individuals without Misting (Table 1). These natural enemy insects belong to five orders: Araneae, Coleoptera, Dermaptera, Diptera, and Hymenoptera. The identification results showed 33 genus, including *Lycosa* sp., *Amphidraus* sp., *Evarcha* sp., *Heliophanus* sp., *Myrmarachne* sp., *Neonella* sp., *Thomisus* sp., *Dromius* sp., *Paratachys* sp., *Tachys* sp., Atheta sp., Carpelimus sp., *Euplectus* sp., *Lithocharis* sp., *Oligota* sp., *Paederus* sp., *Xantholinus* sp., *Euborellia* sp., *Megaselia* sp., *Aphytis* sp., *Encarsia* sp., *Eretmocerus* sp., *Stigmus* sp., *Chelonus* sp., *Basalys* sp., *Aenasius* sp., *Dolichoderus* sp., *Solenopsis* sp., *Pheidole* sp., *Anagrus* sp., *Telenomus* sp., *Oligosita* sp., and *Trichogramma* sp.

In cocoa fields, natural enemies with misting were classified into 4 orders, 16 families, and 31 genera, while in fields without misting treatment, they consisted of 5 orders, 11 family, and 19 genus. These results indicate that higher populations of natural enemy insects were found in cocoa fields treated with misting. The application misting creates a more humid microhabitat, which helps stabilize the insect habitat. These findings are consistent with Hasinu et al., (2024) who stated that humid conditions can increase the comfort required by insects. The results from observing natural enemy insects found in cocoa fields with and without misting treatment, as well as their roles and population numbers, are shown in Table 1.

Table 1. Natural enemy population found in cocoa fields with and without misting

Classification			Roles	Population	
Order	**Family**	**Genus**		***Misting***	**Without Misting**
Araneae	Lycosidae	*Lycosa*	Predators	5	2
	Salticidae	*Amphidraus*	Predators	1	0
		Evarcha	Predators	1	0
		Heliophanus	Predators	1	0
		Myrmarachne	Predators	8	3
		Neonella	Predators	1	0
	Thomisidae	*Thomisus*	Predators	1	0
Coleoptera	Carabidae	*Dromius*	Predators	163	154
		Paratachys	Predators	17	6
		Tachys	Predators	2	0
	Staphylinidae	*Atheta*	Predators	2	4
		Carpelimus	Predators	5	3
		Euplectus	Predators	0	1
		Lithocharis	Predators	1	0
		Oligota	Predators	1	0
		Paederus	Predators	8	0
		Xantholinus	Predators	0	2
Dermaptera	Anisolabididae	*Euborellia*	Predators	34	9
Diptera	Phoridae	*Megaselia*	Parasitoids	14	53
Hymenoptera	Aphelinidae	*Aphytis*	Parasitoids	7	10
		Encarsia	Parasitoids	5	5
		Eretmocerus	Parasitoids	1	1
	Braconidae	*Chelonus*	Parasitoids	1	0
	Crabronidae	*Stigmus*	Predators	2	0
	Diapriidae	*Basalys*	Parasitoids	1	0
	Encyrtidae	*Aenasius*	Parasitoids	1	0
	Formicidae	*Dolichoderus*	Predators	77	7
		Solenopsis	Predators	28	25
		Pheidole	Predators	4	0
	Mymaridae	*Anagrus*	Parasitoids	18	8
	Scelionidae	*Telenomus*	Parasitoids	638	359
	Trichogrammatidae	*Oligosita*	Parasitoids	1	2
		Trichogramma	Parasitoids	4	4
Grand Total				**1053**	**658**

The highest percentage indicated that the order Hymenoptera was found in both cacao fields, accounting for 74.83% under misting treatment and 63.98% without misting treatment (Figure 2). The order Coleoptera ranked second, with 18.90% under misting treatment and 25.84% without misting treatment. Other orders identified with and without misting treatment included Dermaptera (3.23% and 1.37%), Araneae (1.71% and 0.76%), and Diptera (1.33% and 8.05%). The order Hymenoptera represents an insect group with a high population percentage and plays a significant role in the ecosystem, both as natural enemies that help suppress pest populations and as pollinators that support the process of plant reproduction (Perfecto et al., 2014).

The presence of Hymenoptera in cacao fields is influenced by the condition of the plants that have entered the generative phase and begun flowering. The availability of flowers provides essential nutritional resources in the form of nectar and pollen, which directly contribute to increasing abundance of natural enemies (Idris et al., 2023). Furthermore, insects belonging to the order Hymenoptera possess a high adaptive capacity to diverse environmental conditions. This ability enables them to survive and proliferate in large populations, thereby reinforcing their ecological role in maintaining ecosystem balance.

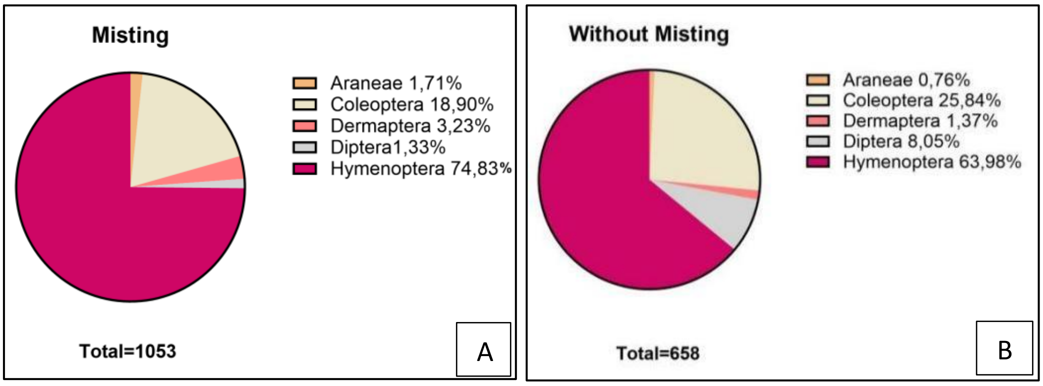

Figure 2. Comparison insect natural enemy population in cocoa fields based on order: (a) misting (b) without misting.

The role of insects as parasitoids and predators was found to be higher in cocoa fields with misting treatment compared to those without misting (Figure 3). The population of predatory insects recorded in cocoa fields with misting was 362 individuals, while 216 individuals were found in fields without misting. Meanwhile, the population of parasitoid insects in cocoa fields with misting reached 691 individuals, compared to 442 individuals in fields without misting. According to Oliveira et al. (2024), the abundance of parasitoid insects, particularly those belonging to the order Hymenoptera, family Scelionidae, and genus *Telenomus* sp., is closely associated with the availability of *Spodoptera* sp. hosts, which are commonly found in cocoa cultivation areas. In addition to the Scelionidae family, the Carabidae family with the genus *Dromius* sp. also serves as an important predator in controlling aphid pests, thereby supporting the food chain balance for ground beetles (Préville et al., 2022).

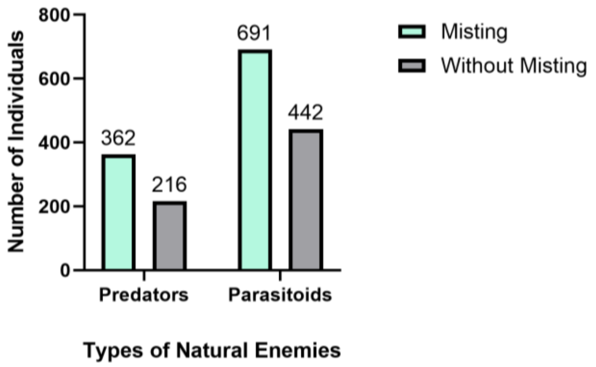

Figure 3. Population predators and parasitoids in cocoa fields

Figure 4. Genus and population of the highest natural enemies in cocoa fields. (a) parasitoids *Telenomus* sp.; (b) predators *Dromius* sp.

Telenomus sp. is a very small insect, measuring about 0.8 mm, with a black body and hind wings smaller than the forewings. It has geniculate type antennae consisting of 10–11 segments, with the terminal part comprising 3 segments (Figure 4.a). The abundance of *Spodoptera* sp. eggs is the main factor contributing to the increase in the number of *Telenomus* parasitoids. Ardina et al. (2024) stated that *Telenomus* is a parasitoid that can be reared with substitute hosts and is effective in controlling pests at the egg stage, achieving up to 64%. Thus having potential as a biological control agent (Otim et al., 2021)

Dromius sp., according to Makwela et al. (2023), belongs to ground beetles that play an ecological role in pest control. Its distinct morphological characteristics include a hard, shiny blackish brown body with a body length of 6 mm. Physical characteristics include an abdomen with striped patterns, three pairs of spiny legs, and an oval-rounded head with elongated antennae consisting of 11 segments (Figure 4.b), functioning as sensory (Rosiana, 2020).The abundance of *Dromius* sp. is influenced by humid environments, as members of the family Carabidae do not favor excessively dry conditions, which can hinder reproduction (Babko et al., 2020). Additionally, the presence of landscape or habitat structures such as leaf litter can also increase abundance by providing shelter (Lemic et al., 2017).

Value of Diversity, Evenness, Richness, and Dominance of Insect Natural enemy

The diversity of natural enemy insects plays an important role in maintaining ecosystem balance. The diversity index (H') in cocoa fields with misting was 1.53, without misting was 1.49 (Table 2.). According to Nurmianti et al. (2015) diversity index values ranging from 1–3 are categorized as moderate. This indicates that the ecosystem conditions of both cocoa cultivation areas are relatively stable and sufficiently diverse, without any insect species dominating excessively. The evenness index (E') in cocoa fields with misting was 0.44, and without misting it was 0.50. These values fall into the unstable category, which means that natural enemy species are not evenly distributed. This imbalance is influenced by external factors such as excessive rainfall, which disrupts the balance of natural enemy insect activities on the soil surface (Fitri et al., 2022).

The species richness index (R') showed a value of 4.31 in cocoa fields with misting, while fields without misting recorded 2.77. The higher richness index with misting treatment is influenced by the increased humidity provided by misting, which in turn enhances abundance of natural enemies. This finding is consistent with Hasinu et al., (2024), who stated that optimal humidity strongly affects insect activity, because the insect body is covered by an integument coated with chitin and composed largely of water, thus requiring adequate humidity to carry out normal metabolic and reproductive processes (Kusuma et al., 2025). The dominance index (C') revealed that cocoa fields with misting obtained a value of 0.40, while those without misting had 0.36. A dominance index value of less than 1 indicates that the abundance of natural enemies in a given area is diverse, with no single species domination (Sembiring, 2020).

Table 2. Values of diversity, evenness, richness and dominance index in cocoa fields

Index	Misting	Without Misting	P - value	Significant
Diversity Index (H')	1,53	1,49	0,01	Significant
Evenness Index (E')	0,44	0,50	0,04	Significant
Richness Index (R')	4,31	2,77	0,03	Significant
Dominance Index (C')	0,40	0,36	0,14	Not Significant

The results of t-test analysis on the diversity index, evenness index, and species richness index showed a p-value < 0.05 in both cocoa plantations. This indicates that there were significant differences in these three indices between the misting and non-misting treatments. In contrast, the dominance index exhibited a p-value > 0.05, suggesting that there was no significant difference between the two treatments. These findings demonstrate that the structure of the natural enemy insect community in cocoa plantations is unstable (Husamah et al., 2016). An unstable community structure is characterized by significant differences in the diversity, evenness, and species richness indices. Therefore, community stability is closely related to environmental changes, which can substantially influence community balance (Jarzyna et al., 2022).

Table 3. Correlation of temperature and humidity with natural enemy populations

Climate Factor	R -Square	t - count	Sig
Temperature	0.001	0.230	0.819
Humidity	0.123	3.315	0.001

The regression analysis of the relationship between temperature and insect population showed an R-square value of 0.001. This R-square value obtained (Table 3) indicates that only 1% of the variation in insect population can be explained by the temperature variable, while the remaining 99% is influenced by other factors not included in the model (Ardiyani et al., 2025). The significance value (sig) obtained was 0.819, which is greater than 0.05, indicating that temperature does not have a significant effect on the increase in insect population (Sianipar et al., 2018). The t-value of 0.816 further confirms that the regression coefficient is not statistically significant. According to Wulandari et al., (2024), insect populations fluctuate over time either increasing or decreasing depending on ecological factors, food availability, habitat conditions, and interactions among organisms. The air temperature recorded during the study ranged from 21-28 °C, which is considered optimal for the development of larvae, pupae, and adult insects (Hasinu et al., 2024).

The regression analysis of the relationship between humidity and insect population showed an R-square value of 0.123. This R-square value indicates that only 12.3% of the variation in insect population can be explained by the humidity variable, while the remaining 87.7% is influenced by other factors not included in the model. The significance value (sig) of 0.001, which is lower than 0.05, indicates that humidity has a significant effect on increase the diversity of natural enemy in cocoa cultivation areas within the net house, although its statistical contribution is relatively small. The t-value of 3.315 further supports that the resulting regression coefficient is statistically significant, indicating that increased humidity has a positive effect (Clario et al., 2025). The humidity range recorded during the study was 56–96%. High humidity conditions can accelerate the insect life cycle and influence their host-searching behavior (Anggara, 2015). A more humid environment can also reduce the risk of dehydration, allowing insects to remain active for longer periods while searching for hosts.

The effect of temperature on abundance of natural enemies was found to be non significant, presumably because the microclimatic conditions within the net house were relatively stable, so daily fluctuations were not large enough to influence insect population dynamics. According to Chien (2019) high environmental stability indicates that the net house functions as a buffer capable of dampening temperature variations, resulting in minimal selective pressure. Therefore, insect population dynamics within the net house are not largely influenced by temperature. Humidity showed a significant but relatively small effect, indicating that it is not the primary factor contributing to the increase in insect populations. Other factors, such as the availability of hosts as nutritional resources supporting insect survival, as well as ecological interactions among organisms, play a more substantial role and contribute to maintaining the overall balance of the ecosystem.

CONCLUSION

Misting significantly increased the abundance and richness of natural enemies, particularly parasitoids from the Hymenoptera order, but its effect on community evenness and dominance was less clear. This suggests that misting can be an effective ecological engineering technique within an IPM framework to enhance biological control services. Interestingly, the microclimatic conditions created were favorable enough to support insect diversity, although there is no significant correlation with temperature, it is significant with humidity.

RECOMMENDATION

Future studies should investigate the long term effects of misting and its integration with other IPM components.

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