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RESEARCH PAPER

The presence of beneficial insects and damage intensity of cocoa pod borer (*Conopomorpha cramerella* Snellen) in plantations with and without insectary plants

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ABSTRACT

The cocoa pod borer (CPB), *Conopomorpha cramerella* Snellen, is one of the most significant pests of cocoa, capable of damaging pods and reducing production. Synthetic insecticides are predominantly used to control this pest; therefore, alternative methods that are environmentally friendly and do not harm non-target organisms are needed. This study aims to determine the role of beneficial insect occurrence, enhanced by insectary plants, in reducing the severity of pod damage and yield loss caused by CPB. The research was conducted by comparing two one-hectare farms, one with and one without insectary plants. The beneficial insects observed included pollinators, predators, parasitoids, decomposers, and herbivores. Their populations were higher on the farm with insectary plants than on the farm without, with pod damage severity of 16.8% and 32.8%, respectively. These data indicate that cultivating insectary plants on cocoa farms can aid in pest management, particularly for CPB, and has the potential to be implemented on a larger scale, as CPB attack intensity was lower on the farm with insectary plants.

Key words: Beneficial insect, *Conopomorpha cramerella*, insectary plants, pod borer

INTRODUCTION

Cocoa (*Theobroma cocoa* L.) is an agricultural commodity that plays an essential role in the Indonesian economy. It is the third most important agricultural export product after palm oil and rubber (Geo & Saediman, 2019). Based on field observations, cocoa crop production has shown a declining trend; in 2014, with a cultivated area of 1,727,437 ha, production reached 728,414 tons, but it decreased to 650,612 tons in 2022 (Directorate of Food Crops, Horticulture, Estate Crops Statistics, 2022). The decline in cocoa production is attributed to factors such as the aging of plants (Geo & Saediman, 2019), soil nutrient depletion, deteriorating farm conditions, imperfect flower formation and pollination, as well as infestations by plant pests (Etaware, 2022). One major pest is the cocoa pod borer (*Conopomorpha cramerella* Snellen), which damages the pods by boring into the pod wall and feeding on placental tissue. This disrupts pod development, causing them to harden, ripen prematurely, and produce flat beans (CABI, 2022).

Efforts to control the cocoa pod borer (CPB) pest generally involve the use of chemical insecticides, which can have negative effects on the environment and reduce the fertility of cocoa plantations (Tripathi et al., 2020). This is because chemical insecticides with toxic and harmful properties can easily leach into the soil, alter its characteristics, and persist for extended periods (Baweja et al., 2020). In addition, the continuous use of insecticides can lead to the development of pest populations that are more tolerant or resistant to these chemicals (Bauddh et al., 2020). Therefore, the management of agroecosystems—such as by growing insectary plants on cocoa farms—offers an environmentally friendly alternative aligned with Integrated Pest Management (IPM) principles. Insectary plants are flowering plants that serve as sources of nectar and pollen, attracting insect parasitoids and predators that feed on pest species. These plants enhance the effectiveness of biological pest control (Bennett, 2018; Morandin et al., 2016). As a result, insectary plants can increase the abundance of key natural enemies, helping to maintain pest populations at non-damaging levels (Armengot et al., 2020; Shrestha et al., 2019).

When selecting insectary plant species to be

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planted, the main goal is to maximize the abundance and diversity of flowering throughout the season. Therefore, the selection of insectary plants on a farm flower color, flowering duration, growth periode, availability, affordability, ease of cultivation, and rapid flowering (Bennett, 2018).

Among the insectary plants that are widely used are the chicken mole flower (*Tagetes erecta* L.), paper flower (*Zinnia elegans* L.), knob flower (*Gomphrena globose* L.), chicken jager flower (*Celosia argentea* var. *cristata*), and sunflower (*Helianthus annuus* L). These plants are easy to find and grow, making them highly suitable for planting on cocoa farms, where they can attract predators and parasitoids (Ichsan et al., 2021).

In addition, planting insectary plants in a polyculture system offers many benefits, such as improving soil health, controlling pests and diseases, suppressing weeds, and increasing crop production (Bauddh et al., 2020). Therefore, the purpose of this study was to determine the role of insectary plants in increasing arthropod populations and their impact on the intensity of cocoa pod damage and yield loss caused by *C. cramerella*. It is hypothesized that refugia plants can enhance the population of beneficial predators and parasitoids, thereby significantly controlling *C. cramerella.*

MATERIALS AND METHODS

Research Site. This research was conducted from March to July 2022 in a cocoa plantation located in Gantarangkeke Village, Bantaeng Regency, South Sulawesi, and at the Pest Science Laboratory, Department of Plant Pests and Diseases, Faculty of Agriculture, Hasanuddin University, Makassar, Indonesia.

Treatment. The experimental site consisted of two cocoa farms planted with S2 cocoa clones, each covering an area of 1 ha. One of the farms was intercropped with insectary plants, including *T. erecta L., Z. elegans, G. globosa* L., *C. argentea* var. *cristata*, and *H. annuus* L.) (Figure 1). In contrast, the second farm had no insectary plants. Insectary plants were planted in clusters and scattered throughout the cocoa plantation, particularly along the edges and in the middle of the field.

Intensity of CPB Attack. Observations on both farms focused on infestation by the CPB, *C. cramerella,* as well as the presence of beneficial insects such as pollinators, predators, decomposers, and parasitoids. CPB attack observations were conducted by sampling cocoa pods from two types of fields: those managed with insectary plants and those managed according to traditional farmer practices (without insectary plants).

In each farm, five observation points were selected following a diagonal (X-shaped) pattern. At each point, five cocoa trees were chosen, marked, and numbered using paint or labels. From each tree, four mature pods were randomly selected, yielding a total of 20 pods per point and 100 pods per field per observation. After harvest, pods were split open using a knife, and the number of sticky seeds (an indicator of CPB attack) was recorded. Observations were conducted eight times at two-week intervals over four months.

Observations of Beneficial Insects. Observations of beneficial insects were carried out using three methods: direct visual observation by directly observing by eye,

Figure 1. Insectary plants. A. *T. erecta* L.; B. *Z. elegans*; C. *G. globose* L.; D. *C. argentea var. cristata*; E. *H. annuus* L.

sweep net by swinging the net three times, and yellow sticky traps by attaching glue traps to stakes placed above ground. Sampling was conducted in both types of cocoa farms (with and without insectary plants). At each location, five sampling points were selected using a diagonal line pattern, and five cocoa plants were chosen at each end.

Observations began with flower emergence and continued through pod formation. These were conducted eight times at one-week intervals over a two-month period. Insect sampling on insectary plants was performed on all five species. For each species, three well-developed, non-adjacent sample plants were selected. Observations were similarly conducted eight times at weekly intervals. Subsequently, arthropods collected during the observations were identified morphologically, and their ecological roles were determined.

Statistical Analysis. Pod damage parameters were analyzed by calculating the average intensity of CPB attack. Pod damage and yield loss were analyzed using the linear regression method. The CPB attack intensity was calculated using the following formula (Lee et al., 1995):

$$IS = \frac{(\Sigma B \times 0.093) + (\Sigma C \times 0.297) + D}{\Sigma(A + B + C + D)} \times 100\%$$

IS = Attack intensity CPB on cocoa pod;
A = Not attacked;
B = Low attacked;
C = Medium attacked;
D = Heavy attacked.

Attack intensity was categorized as follows:
Category B = 1%–10% damage, seeds can be removed by hand;
Category C = 11%–50% damage, seeds can be removed using tools;
Category D = ≥ 50% damage, seeds cannot be removed even with tool.

Scale values for each attack intensity category are presented in Table 1 (Natawigena, 1992). To determine the correlation between pod damage and yield loss, linear regression was performed following Pratama et al. (2021):

$$Y = a + bX$$

Y = Cocoa yield loss;
a = Constant;
b = Regression coefficient;
X = CPB attack intensity (%).

The linear regression data were analyzed using the F-test with an analysis of variance (ANOVA) at the 5% significance level.

RESULTS AND DISCUSSION

CPB Attack Intensity. The results of observations on the average attack intensity of the CPB, *C. cramerella,* on cocoa farms managed with insectary plants and those without are presented in Figure 2.

Different symbols in each observation indicate significant differences between treatments with and without insectary plants (Figure 2). The attack intensity of CPB was consistently higher on cocoa farms without insectary plants compared to those with insectary plants. In the fourth observation, the attack intensity decreased on farms with insectary plants but increased on those without. Over eight observation periods, significant differences in attack intensity were observed, except during the third and fifth observations. Overall, the higher CPB attack intensity on farms without insectary plants may be attributed to the lower population of beneficial insects (Figure 3), which naturally suppress pest populations

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Populations of Beneficial Insects. Figure 3 shows the populations of beneficial insects in cocoa plantations with and without insectary plants, classified by their ecological roles: pollinators, predators, decomposers, and parasitoids. These beneficial insects were significantly more abundant in cocoa farms with

Tablel 1. Criteria for assessing the intensity of attacks

Scale	Pod damage severity	Category
0	0	Normal
1	$1 < x \leq 25$	Low
2	$25 < x \leq 50$	Medium
3	$50 < x \leq 75$	Heavy
4	$x > 75$	Very heavy

Source: Natawigena (1992).

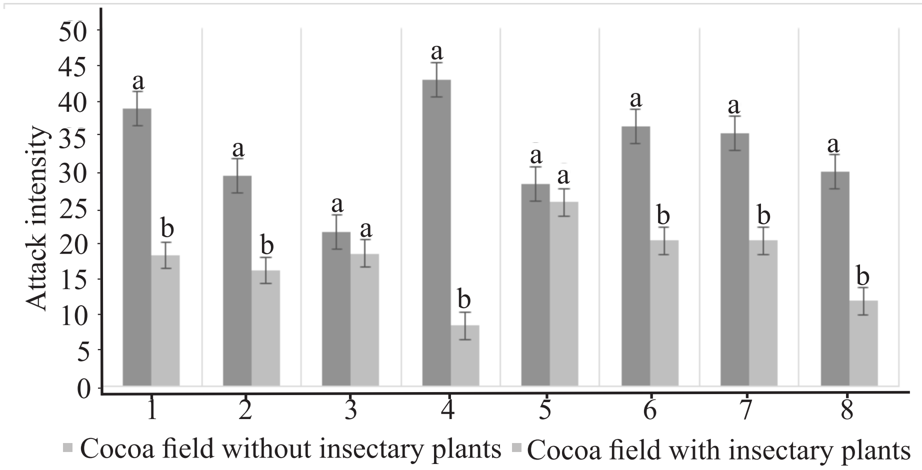

Figure 2. Intensity of attack by CPB on cocoa farm with and without insectary plants.

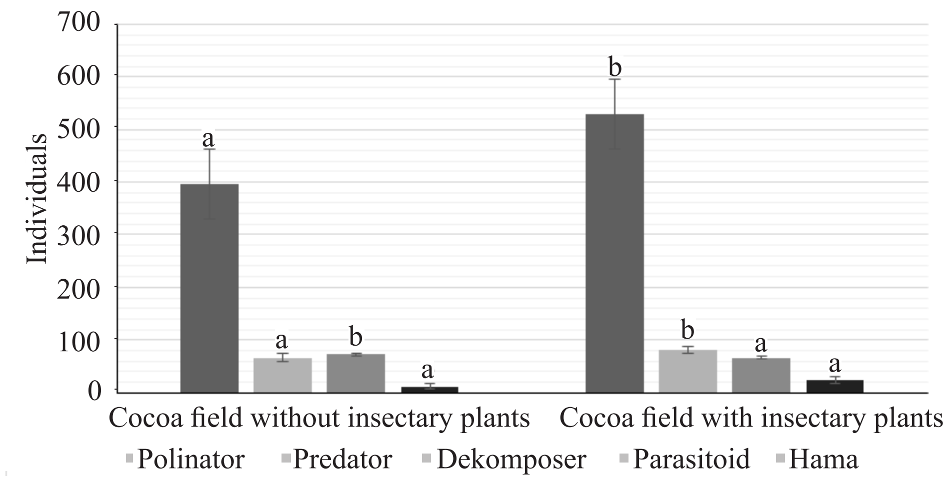

Figure 3. Beneficial insect populations on cocoa plantations.

insectary plants. This indicates that increased plant diversity in cocoa plantations enhances the presence of beneficial insects capable of controlling pest populations.

A linear regression analysis revealed a significant negative correlation between the population of beneficial insects and CPB attack intensity. It was found that for each 1% increase in the beneficial insect population, CPB attack intensity decreased by 0.41% (Figure 4).

Relationship Between Beneficial Insect Population and CPB Attack Intensity. Figure 5 illustrates the average population of beneficial insects found on each type of insectary plant used. Insectary plants can enhance on-farm biodiversity, protect water quality, and provide habitats for beneficial insects such as native bees and natural enemies (Morandin et al., 2016). Cocoa agroecosystems with diversified cropping systems tend to have lower pest and disease incidence compared to monoculture systems, ultimately increasing productivity (Armengot et al., 2020).

The insectary plants used in this study are common flowering species that attract various beneficial insects due to their differing floral characteristics (Figure 5). The polyculture system has been shown to enhance garden ecosystem biodiversity (Altieri, 1999; Pickett et al., 2014). Predators help suppress pest populations, reducing pest attack intensity, while pollinators increase flower pollination, improving pod production.

Among the insectary plants, *Tagetes erecta* L. attracted the highest number of arthropods, with a total population of 118 individuals (Table 2). In organic cocoa farms, arthropod populations are 50% higher than in conventional (inorganic) farming systems. Soil-surface-active arthropods, especially from the Formicidae family (order Hymenoptera), were more abundant in organic systems and acted as effective predators (Dewi et al., 2020).

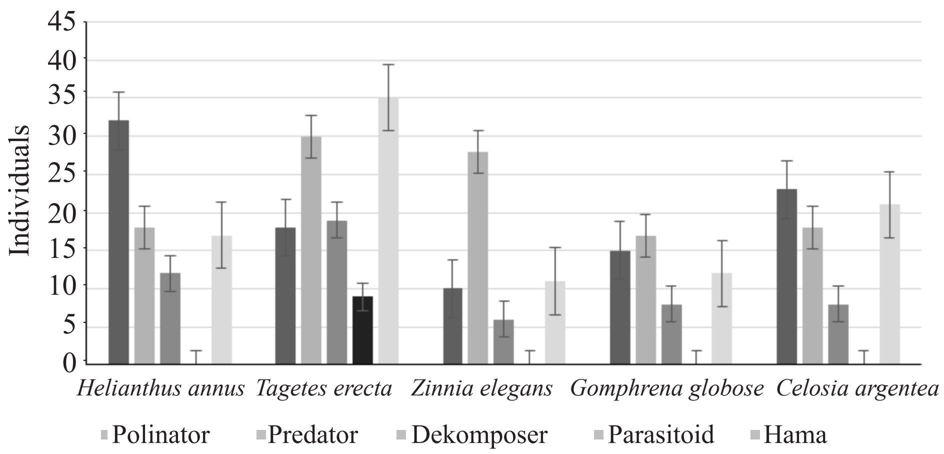

Figure 4. Average population of beneficial insects in various insectary plants.

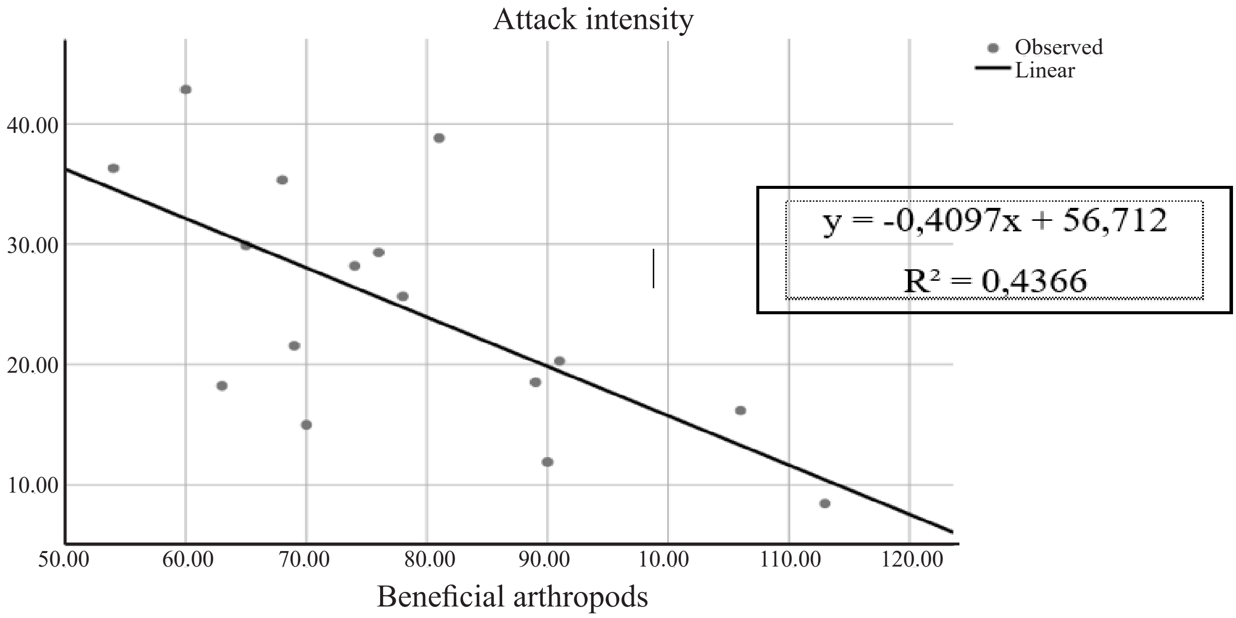

Figure 5. Graph of the effect of the presence of beneficial insects on the intensity of attacks by CPB.

Arthropod Species. Arthropods found in the five insectary plant species included:
H. annuus L.: dominated by pollinators, consisting of five species from the orders Diptera and Hemiptera;
T. erecta L.: dominated by pests, comprising nine species from the orders Hemiptera, Lepidoptera, Mantodea, and Orthoptera;
Z. elegans Jaqc.: dominated by predators and pollinators, with six species each from the orders Araneae, Hymenoptera, Odonata, and Lepidoptera;
G. globosa L.: dominated by pollinators, with six species from the orders Diptera, Hymenoptera, and Lepidoptera;
C. argentea var. *cristata*: dominated by pollinators, with seven species from the orders Hymenoptera, Diptera and Lepidoptera.

T. erecta L. stood out as a refugia plant with a high number of predator and parasitoid species, highlighting its strong attraction to natural enemies compared to the other insectary plants.

Plant Production. Insectary plants are flowering plants that have nectar or pollen which is a food source for some insects. Beneficial insect populations can be boosted by growing flowering plants that provide nectar and pollen. Flower resources are essential to support beneficial insects because some predators and parasitoids only become predators in one life stage, meaning that non-predatory life stages feed on pollen and nectar as a source of energy (Bennett, 2018). Pollinator insects on cocoa plantations function to speed up the process of pollinating flowers on cocoa

Table 2. Arthropods on various insectary plants

Insectary Plant	Class	Order	Family	Spesies	Status	Total
H. annuus L.	Arachnida	Araneae	Tetragnathidae	*Tetragnatha mooimeinensis*	Predator	6
	Insecta	Coleoptera	Coccinellidae	*Epilachna admirabilis*	Predator	11
		Odonata	Libellulidae	*Pantala flavescens*	Predator	1
		Diptera	Ceratopogonidae	*Forcipomyia* sp.	Pollinator	5
		Hymenoptera	Apidae	*Apis cerana*	Pollinator	12
				Bombus vertalis	Pollinator	4
				Xylocopa violacea	Pollinator	1
			Formicidae	*Irrydormex* sp.	Predator	10
		Diptera	Stratiomyidae	*Hermetia illucens*	Decomposer	12
		Coleoptera	*Chrysomelidae*	*Altica cyanea* Weber	Pest	1
		Diptera	Drosophillidae	*Drosophila melanogaster*	Pest	4
		Hemiptera	Plataspididae	*Brachyplatys* sp.	Pest	7
		Orthoptera	Acrididae	*Locusta migratoria manilensis* Meyen	Pest	5
				Total		79
T. erecta L.	Arachnida	Araneae	Lycosidae	*Lycosa pseudoannulata*	Predator	5
			Oxyopidae	*Oxyopes javanus*	Predator	5
			Theridiidae	*Cryptachaea porteri*	Predator	1
			Thomisidae	*Thomisius sp.*	Predator	10
	Insecta	Hymenoptera	Diapriidae	*Basalys* sp.	Predator	5
		Odonata	Libellulidae	*P. flavescens*	Predator	2
		Orthoptera	Gryllidae	*Acheta domesticus*	Predator	2
		Coleoptera	Cerambycidae	*Batus barbicornis*	Pollinator	6
		Diptera	Ceratopogonidae	*Forcipomyia* sp.	Pollinator	9
			Limoniidae	*Molophilus* sp.	Pollinator	3
		Diptera	Stratiomyidae	*H. illucens*	Decomposer	19
		Diptera	Tachinidae	*Argyrophylax* sp.	Parasitoid	9
		Orthoptera	Tettigoniidae	*Phaneroptera falcata*	Netral	7
		Hemiptera	Alydidae	*Leptocorisa oratorius*	Pest	10
			Thyreocoridae	*Brachyplatys* sp.	Pest	4
		Lepidoptera	Erebidae	*Dasychira inclusa*	Pest	1
			Gracillariidae	*C. cramerella*	Pest	1
		Mantodea	Mantidae	*Hierodula patellifera*	Pest	2
		Orthoptera	Acrididae	*Acrida conica*	Pest	6
				Valanga nigricornis	Pest	5
			Tettigoniidae	*Tetrigidae* sp.	Pest	1
			Pyrgomorphidae	*Atractomorpha* sp.	Pest	5
				Total		118

Table 2. Continued. Arthropods on various insectary plants

Insectary Plant	Class	Order	Family	Spesies	Status	Total
Z. elegans Jaqc.	Arachnida	Araneae	Lycosidae	*L. pseudoannulata*	Predator	3
	Insecta	Hymenoptera	Formicidae	*Dolichoderus thoracicus*	Predator, Pollinator	9
				Oecophylla smaragdina	Predator	8
		Odonata	Coenagrionidae	*Ischnura hastata*	Predator	2
			Libellulidae	*Diplacodes trivialis*	Predator	1
				Orthetrum sabina	Predator	5
		Hymenoptera	Apidae	*B. vertalis*	Pollinator	2
				Trigona laeviceps	Pollinator	1
			Formicidae	*Irrydormex* sp.	Predator	5
		Lepidoptera	Nymphalidae	*Cupha erymanthis*	Pollinator	1
				Vindula erota	Pollinator	1
		Diptera	Stratiomyidae	*H. illucens*	Decomposer	6
		Coleoptera	Chrysomelidae	*Charidotella sexpunctata*	Pest	2
		orthoptera	Acrididae	*L. migrotoria manilensis* Meyen	Pest	2
				Melanoplus femurrubrum	Pest	1
				Oxya fuscovittata	Pest	6
G. globose L.	Insecta	Dermaptera	Forficulidae	*Forficula* sp.	Predator	3
		Hymenoptera	Formicidae	*O. smaragdina*	Predator	10
			Diapriidae	*Basalys* sp.	Predator	4
		Diptera	Ceratopogonidae	*Forcipomyia* sp.	Pollinator	5
			Limoniidae	*Molophilus* sp.	Pollinator	2
		Hymenoptera	Apidae	*A. dorsata*	Pollinator	1
				X. violacea	Pollinator	1
			Formicidae	*Irrydormex* sp.	Predator	5
		Lepidoptera	Nymphalidae	*Hypolimnas bolina*	Pollinator	1
		Diptera	Stratiomyidae	*H. illucens*	Decomposer	8
		Hemiptera	Plataspididae	*Brachyplatys* sp.	Pest	3
		orthoptera	Acrididae	*V. nigricornis*	Pest	4
			Pyrgomorphidae	*Atractomorpha* sp.	Pest	2
				Atractomorpha crenulata	Pest	3
				Total		52
C. argentea var. *cristata*	Arachnida	Araneae	Tetragnathidae	*T. mooimeinensis*	Predator	2
	Insecta	Coleoptera	Coccinellidae	*E. admirabilis*	Predator	7
		Hymenoptera	Formicidae	*D. thoracicus*	Predator, Pollinator	5

Table 2. Continued. Arthropods on various insectary plants

Insectary Plant	Class	Order	Family	Spesies	Status	Total
		Orthoptera	Gryllidae	*A. domesticus*	Predator	4
		Diptera	Syrphidae	*Episyrphus balteatus*	Pollinator	1
			Colletidae	*Hylaeus modestus*	Pollinator	1
			Limoniidae	*Molophilus* sp.	Pollinator	4
		Hymenoptera	Formicidae	*Irrydormex* sp.	Predator	9
			Halictidae	*Lasioglossum malachurum*	Pollinator	1
		Lepidoptera	Nymphalidae	*Doleschallia* sp.	Pollinator	7
		Diptera	Stratiomyidae	*H. illucens*	Decomposer	8
		Diptera	Drosophillidae	*D. melanogaster*	Pest	3
		Hemiptera	Alydidae	*L. oratorius*	Pest	1
			Thyreocoridae	*Brachyplatys* sp.	Pest	6
		Orthoptera	Acrididae	*O. fuscovittata*	Pest	11
				Total		70

plants, so that they produce ovaries quickly.

This is consistent with the production yields on cocoa farms with higher insectary plants compared to those without insectary plants (Figure 6). Cocoa pod borer pests can be controlled through good cultivation techniques during cocoa plantation management (Niogret et al., 2022) and polyclone planting to increase the diversity of beneficial insects (Bennett, 2018).

The production results show that the presence of insectary plant can increase production yields which are significantly different from farm without insectary plants. Insectary plants can be an environmentally friendly alternative control at an affordable cost; besides that, insectary plants can be used successively because they will always grow and spread on planted land. CPB is a major pest on *Theobroma cocoa* which is economically influential in Southeast Asia (Niogret et al., 2022). CPB attacks greatly affect annual cocoa production, with yield losses due to CPB attack ranged from 18.25% to 73.04% (Silalahi, 2022).

CPB causes losses to cocoa by boring into the placental tissue and pod walls, thus interfering with the development of the beans. Pods attacked by CPB pests can cause prematurely ripe pods, small and flat seeds, and hardened pods (CABI, 2022). Linear regression analysis of the intensity of attack of CPB on production has a significant effect and shows a negative linear graph (Figure 7).

On farm with insectary plants, every 1% increase in attack intensity of CPB caused a yield loss of 3.34% or 3.34 kg. On the hand, in farm without insectary plants, for every 1% increase in attack intensity of CPB caused a yield loss of 2.47% or 2.47 kg. The results of other studies showed that the attack intensity increased by 1%, there would be a yield loss of 17.96 kg/ha (Febriyanti et al., 2021).

Therefore, planting insectary plants is a good cocoa cultural practice that increases insect diversity and the sustainability of the ecosystem services provided by insects (Rosalia et al., 2022).

CONCLUSION

Growing insectary plants in cocoa plantations can have a positive impact on the presence of beneficial insects such as predators, pollinators, parasitoids and decomposers. This leads to a reduction in the intensity of CPB, *C. cramerella,* attacks and increase in production yields. Farms with insectary plants had significantly larger populations of beneficial insects, lower CPB attack intensity, and higher yields. On farms with insectary plants, every 1% increase in CPB attack intensity caused a yield loss of 3.34% or 3.34 kg. On farms without insectary plants, each 1% increase in CPB attack intensity resulted in a yield loss of 2.47% or 2.47 kg. Therefore, it is important to manage the cocoa plantation agroecosystem by planting insectary plants to enhance the population of benefecial insects. All types of refugia plants can attract beneficial insects, especially predators and parasitoids that act as natural enemies. *T. erecta* L. is one of the refugia plants that attracted the highest number of predators and parasitoids compared to other plants species observed.

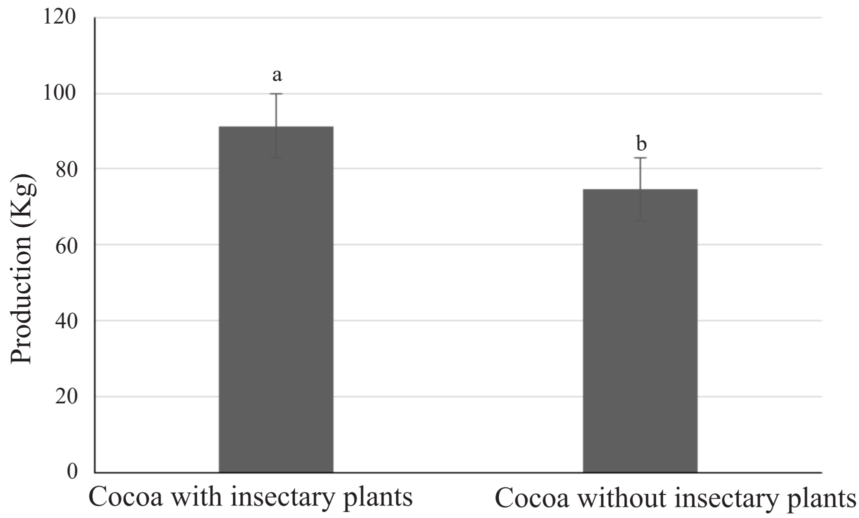

Figure 6. Results of cocoa plantation production.

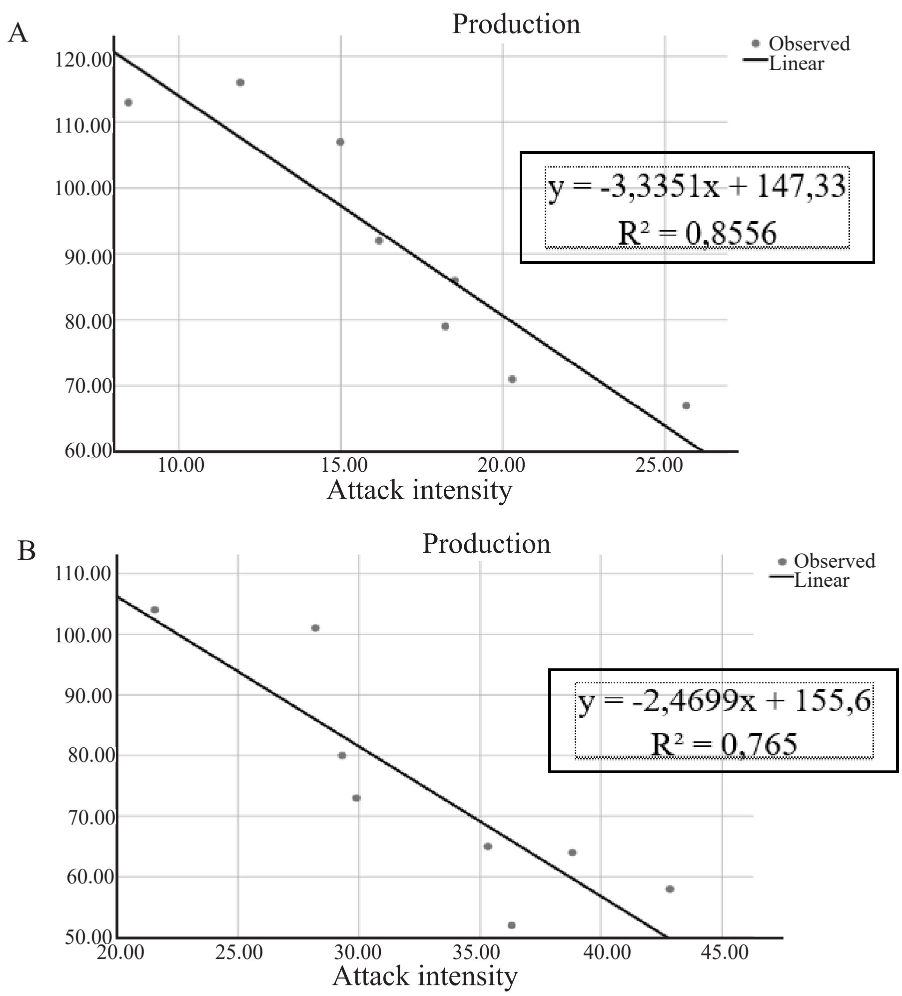

Figure 7. Graph of the effect of *C. cramerella* attack intensity on production. A. with insectary plants; B. Without insectary plants.

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AUTHORS' CONTRIBUTIONS

All authors contributed to the conceptualization, research design, implementation, and preparation of this scientific article. The authors were actively involved in providing feedback on the research process, data analysis, interpretation, and manuscript preparation. All authors have read and approved the final version of the manuscript.

COMPETING INTEREST

The authors declared that this study was conducted without any conflict of interest or competing interests.

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