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A Model of Natural Enemies of the Main Pest Hypothenemus Hampei in People's Coffee Plantations in the Lake Toba Area

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The increase in coffee plantation area in the Lake Toba area is dominated by 96% of smallholder plantations. The coffee productivity value is relatively low, which is 810 kg/ha/year compared to the productivity that should reach 2000 kg/ha/year. Farmers have had a long experience, but are not supported by cultivation techniques according to Good Agricultural Practices (GAP) coffee will trigger an increase in attacks by Plant Pest Organisms. Attacks by the coffee berry borer (CBB) *Hypothenemus hampei* and leaf-sucking pests *Helopelthis* sp. can reduce production by up to 50%. The results of the first year's research showed that attacks by leaf-sucking pests *Helopelthis* sp. spread with an attack intensity ranging from 40.38% to 59.61%, causing the shoots to dry out and rosettes to occur. In addition, the relative density of CBB in monoculture coffee planting patterns can reach 27 individuals/night/trap so that farmers' dependence on pesticides continues to increase. The occurrence of this pest problem is one indicator of the imbalance of the coffee plantation ecosystem. The utilization of coffee plantation areas in monoculture has not provided added value per planting area, even though various types of annual plants, both food crops and horticultural plants in the area have the potential to be utilized. Although natural enemies of CBB and *Helopelthis* sp. have been found, there is no information on optimizing the use of natural enemies either by manipulating habitats or applying entomopathogens in the field. The aim of the research was to obtain the type of planting pattern that supports the existence of natural enemies and to obtain biological agents endemic to coffee plantations in the Lake Toba area that have the potential to control CBB. The method used was to increase vegetation diversity, optimize protective plants and augment natural enemies of CBB and *Helopelthis* sp. as the basis for managing Sustainable Coffee Plantation Pests in the Lake Toba Area. The results of the study showed that increasing the diversity of coffee plantation vegetation (polyculture) could reduce abundance almost twofold and suppress the level of CBB attacks by up to 30.76% compared to monoculture planting patterns. Biological agents of entomopathogenic fungi *Beauveria* sp. and *Metarhizium* sp. The results of exploration in coffee plantations were also able to kill CBB using the spraying and fruit soaking methods, namely 47.50% and 100% respectively. The conclusion of the study is that polyculture planting patterns can suppress the CBB population. In addition, two types of entomopathogenic fungi were obtained that have the potential to control CBB, including *Beauveria* sp. and *Metharizium* sp.
Keywords: Augmentation, coffee berry borer (CBB) *Hypothenemus hampei*, conservation, polyculture, vegetation.

INTRODUCTION

Indonesia is ranked 4th as the largest coffee exporting country in the world after Brazil, Vietnam, and Colombia (Manson, 2022). BPS data recorded that coffee exports increased by 7.5% from 335.76 thousand tons in 2019 to 384.51 thousand tons in 2021 (Central Statistics Agency, 2022). Efforts to increase coffee productivity and quality must continue to be carried out so that the competitiveness of coffee in Indonesia can compete in the world market (Dufour *et al.*, 2019). In the management of community coffee plantations, many problems were found, including the failure to implement Good Coffee Cultivation (Good Agriculture Practices/GAP) in accordance with the Regulation of the Minister of Agriculture of the Republic of Indonesia Number 49 of 2014 (Giovannucci and Ponte, 2005). Attacks by coffee berry borer (CBB) pests (*Hypotenemus hampei*) and leaf rust on coffee plantations can reduce production by up to 50% (Dufour *et al.*, 2019). Furthermore (Kuswardani *et al.*, 2023) stated that the *Helopelthis* sp. pest attack spread with an attack intensity ranging from 40.38% to 59.61% causing the shoots to dry out and rosettes to occur, in addition, the relative density of

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Hypothenemus in monoculture coffee planting patterns can reach 27 individuals/night/trap so that coffee farmers' dependence on pesticides continues to increase. To overcome these pest attacks, farmers only use pesticides due to limited technology and science.

Globalization demands a sustainable coffee production system and processing and business processes through certification (Manson, 2022; Giovannucci and Ponte, 2005; Kuswardani *et al.,* 2023). Sustainable coffee management must align economic, social, environmental aspects (Astuti *et al.,* 2012; Adams and Ghaly, 2007; Jaya *et al.,* 2013; Narita, 2014; Krishnan, 2018), as well as to anticipate the impact of global climate change (Rosen, 2018; Syakir and Surmaini, 2017) on coffee commodities (Santaram, 2018), including in Indonesia (Gaitan-Cremaschi *et al.,* 2018). Consumer countries demand quality coffee that is safe for health. The European Union Regulation on Minimum Residue Limits (MRL) of Chlorpyrifos and Gliphosate for food imports including coffee is one of the important reasons for the importance of safe and sustainable coffee cultivation techniques by minimizing the use of pesticides in controlling plant pests (Manson, 2022). The problem that will be studied is the suboptimal utilization of indigenous natural resources (ecological characteristics, natural enemies, refugia, plants (separate, protective plants) in the people's coffee plantations in the Lake Toba area which are used as a model for ecological engineering in sustainable pest management.

MATERIALS AND METHODS

The study was conducted to obtain an ecological engineering model as an implementation of GAP on Arabica community coffee plantations of the Sigarar Tutang variety in the Lake Toba area which has an altitude of 1200 meters above sea level with an average temperature of 21ºC and humidity of 80% and the types of soil, namely Latosol, podsolic, regosol. The study was conducted in two Arabica coffee center sub-districts, namely Ronggor Nihuta District, Samosir Regency and Motung District, Toba Regency, West Sumatra Province, Indonesia. Fungi propagation was carried out at the Plant Protection Laboratory of Medan Area University.

***Materials*:** *Beauveria* sp. and *Metarhizium* sp. fungi from previous exploration, PDA media, alcohol, distilled water, tween 60, aluminum foil, wrapping, tissue, 3% NaOCL, distilled water, label paper, cotton, label paper, stationery, plastic bag books, jars, knives, tweezers, cameras, ropes, ethanol trap sets, filters, cups, 600ml mineral bottles, insect bottles, safety pins, attractant active ingredient ethanol with the trademark koptan, pitfall trap, yellow trap, detergent, and water.

***Methods*:** Application of Indigenous Biological Agents *Beauveria* sp. and *Metharizium* sp. in Controlling *Hypothenemus hampei*. The results of the isolation of *Beauveria* sp. and *Metharizium* sp. fungi from CBB beetles in two coffee plant center villages were propagated in the faculty of agriculture laboratory, University Medan Area namely the testing of fungal isolates based on the Gustianingsih's *et al*. (2021) method. Each test used five treatments, namely control (sterile water) and 4 levels of B. bassiana doses (10^6 and 10^7). The experimental unit in the form of 20 individual adult CBB beetles was arranged using a Complete Randomized Block Design (CRBD) with 3 groups, grouping based on treatment time. Observation parameters: CBB mortality. Mortality rate data were analyzed by linear regression analysis at a 5% significance level. Spore density data were transformed to log10.

***Abundance of CBB in coffee plantations*:** Observation of insect abundance was observed by installing 30 ethanol traps in the form of Hyphotan pheromone in each type of location. Observations were carried out every day for seven days, the treatment was repeated 4 times. The abundance of CBB was calculated in traps (tails/trap/night) and in 100 coffee fruits (tails/fruit) which were taken randomly as samples.

***Percentage and Intensity of CBB attacks*:** Observations of the percentage and intensity of CBB attacks on coffee plants were carried out on each type of plantation. Observations were made on the number of plants attacked and the damage caused by CBB. The number of plants attacked was calculated based on the symptoms of the attack and expressed as a percentage of the attack. The damage caused was calculated based on the severity score and expressed in the intensity of the attack. In each planting pattern, 30% of the sample plants were taken. Observations were made by looking at the symptoms of the attack on the coffee fruit and were scored based on the severity of the attack. The percentage of plants attacked was calculated using the formula Kuswardani *et al.* (2023).

***Abundance of natural enemies in coffee plantations*:** Observations of natural enemies were carried out by installing 10 traps in the form of pitfall traps and yellow traps at each type of location. Observations were carried out every day for seven days, the treatment was repeated 4 times. The abundance of natural enemies was calculated on traps with the identification of orders and families.

RESULTS

***Mortality of CBB after application of entomopathogenic Fungi*:** Based on the research that has been done, it is known that the application of entomopathogenic fungi (*Beauveria* sp. and *Metarhizium* sp.) can cause mortality to CBB (Tables 1 and 2). In the application of entomopathogenic fungi with the spraying method, the treatment of *Beauveria* sp. isolate (BB1) with a concentration of 107 conidia/ml showed the highest mortality value of 47.50%. The lowest mortality value was shown by the treatment of *Metarhizium* sp. (MA2) with a concentration of 10^6 conidia/ml, namely 33.33%. In the treatment of *Metarhizium* sp. fungi (MA1 and MA2) with the coffee fruit soaking method, PBKo mortality reached 100% on the 7th day. All entomopathogenic fungal treatments showed significantly different results compared to the control, namely with a mortality value of 7.5%.

Table 1. Mortality of *H. hampei* after entomopathogenic fungus treatment using the spraying method at 7 days after planting.

Isolates	Mortality of Larvae (%) ± SD
BB1 10^7	47,50 ± 7,90 a
BB1 10^6	42,50 ± 3,10 b
MA1 10^6	36,67 ± 12,8 b
MA2 10^6	33,33 ± 7,50 c
CONTROL	7,50 ± 3,28 d

Numbers followed by the same lowercase letter in the same column indicate results that are not significantly different according to LSD at the 5% level.

Table 2. Mortality of *H. hampei* after treatment with *Metharizium* sp. fungus using the coffee fruit soaking method on the 7th day after.

Isolates	Mortality of Larvae (%) ± SD
MA1 10^6	100 ± 0,0 a
MA2 10^6	100 ± 0,0 a
CONTROL	7,50 ± 7,81 b

Numbers followed by the same lowercase letter in the same column indicate results that are not significantly different according to LSD at the 5% level.

***Symptoms of CBB attack on coffee cherries*:** Based on the research that has been conducted, it is known that CBB is able to attack coffee fruit at all stages of coffee fruit development (Figure 1). Symptoms of attack are more often found in ripe coffee fruit than in young coffee fruit. Coffee fruit attacked by CBB shows symptoms of attack in the form of drill holes on the disc or tip of the coffee fruit. The number of drills on coffee fruit in monoculture plantations is greater (two to three per coffee fruit), compared to polyculture plantations (one per coffee fruit).

Figure 1. Symptoms of CBB attack on coffee cherries: A. Cracking holes in the disk of the coffee fruit, B. Symptoms of attack on young coffee cherries, C. Symptoms of attack on mature coffee cherries, D. Condition of coffee beans attacked by CBB.

***Relative abundance of H. hampei in coffee plantations (tails/trap/night)*:** Based on the research that has been done, it is known that the monoculture planting pattern shows the highest abundance of CBB population compared to the polyculture planting pattern (Table 3). In monoculture planting, the average population of CBB trapped until the 7th day was 70.47 tails/trap with an average population of 10.06 tails/trap/night. This value is almost twice as high as the population in polyculture plantations.

Table 3. Average population of *H. hampei* in coffee plantations (tail/trap/night) based on planting pattern.

Observation Time (day)	Planting Pattern (tail/trap/night)	
	Monoculture	Polyculture
1	1,80	9,70
2	27,13	8,53
3	16,90	2,80
4	14,03	2,03
5	0,77	4,87
6	1,30	5,07
7	8,53	2,73
Total	70,47	35,73
Average	10,06	5,10

***Absolute abundance of H. hampei on coffee berries (tails/fruit)*:** The monoculture planting pattern also showed the highest abundance of CBB population per coffee berry compared to the polyculture planting pattern (Tables 4 and 5).

Table 4. Population of *H. hampei* on coffee cherries (heads/fruit) based on planting patterns in Kab. Toba.

Planting Pattern	No. of coffee fruit samples	Total population	Population by life stage		
			Larvae	Pupae	Adult
Monoculture					
Total	100	467	147	165	155
Average		4,67	1,47	1,65	1,55
Polyculture					
Total	100	180	50	62	68
Average		1,80	0,50	0,62	0,68

Table 5. Population of *H. hampei* on coffee cherries (tails/fruit) based on planting patterns in Kab. Samosir.

Planting Pattern	No. of coffee fruit samples	Total population	Population by life stage		
			Larvae	Pupae	Adult
Monoculture					
Total	100	162	44	63	55
Average		1,62	0,44	0,63	0,55
Polyculture					
Total	100	133	34	39	60
Average		1,33	0,34	0,39	0,60

These results were seen in plantations in Toba Regency and Samosir Regency. In monoculture planting, the CBB population of 100 coffee berries sampled respectively, were 467 tails and 162 tails per 100 seeds with an average population per seed of 4.67 tails/seed and 1.62 tails/seed respectively. This value is higher than the polyculture planting pattern. In monoculture planting, CBB was dominated by the imago phase up to 40.12% and in polyculture planting, CBB was dominated by the pupa phase up to 45.11% (Figure 2).

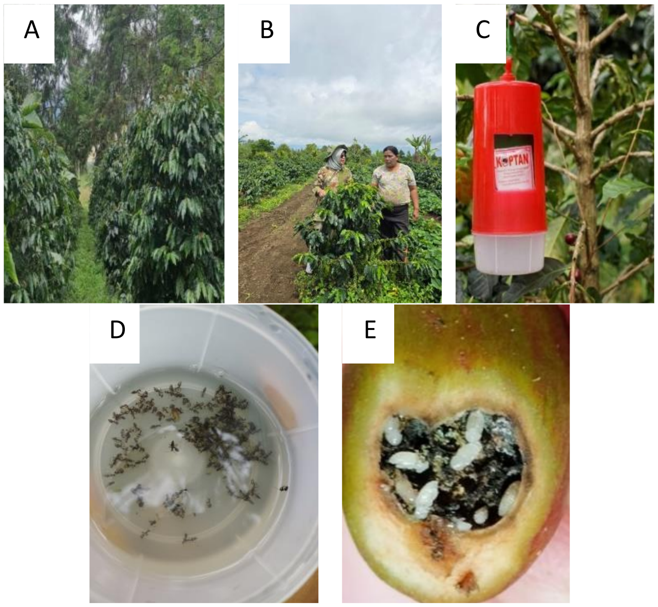

Figure 2. Abundance of CBB in coffee plantations: A. Monoculture planting pattern, B. Polyculture planting pattern, C. Installation of ethanol traps, D. CBB in coffee plantations (tail/trap/wax), E. CBB in coffee berries (tail/fruit).

***Percentage and intensity of CBB attacks on coffee plantations*:** Based on the research that has been conducted, it is known that the monoculture planting pattern shows the highest percentage and intensity of attacks compared to the polyculture planting pattern (Table 6 and Figure 3).

Table 6. Percentage and intensity of CBB attacks on monoculture and polyculture coffee plantations.

Planting Pattern	Attack Percentage (%)	t-test	Intensity attacks	
			Intensity (%)	Damage Category
Monoculture	35,96 %	Significant Influence	47,91 %	Currently
Polyculture	26,00 %	Significant Influence	36,64 %	Currently

In the monoculture planting pattern, the percentage and intensity of attacks were 35.96% and 47.91%, respectively. Although the intensity of CBB attacks on both planting patterns is included in the same category, namely the moderate category, the polyculture planting pattern is able to reduce damage by CBB by up to 30.76%.

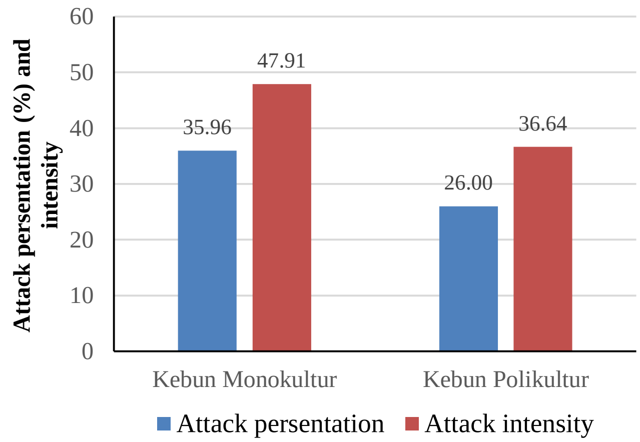

Figure 3. Percentage and intensity of CBB attacks on monoculture and polyculture coffee plantations in Samosir Regency.

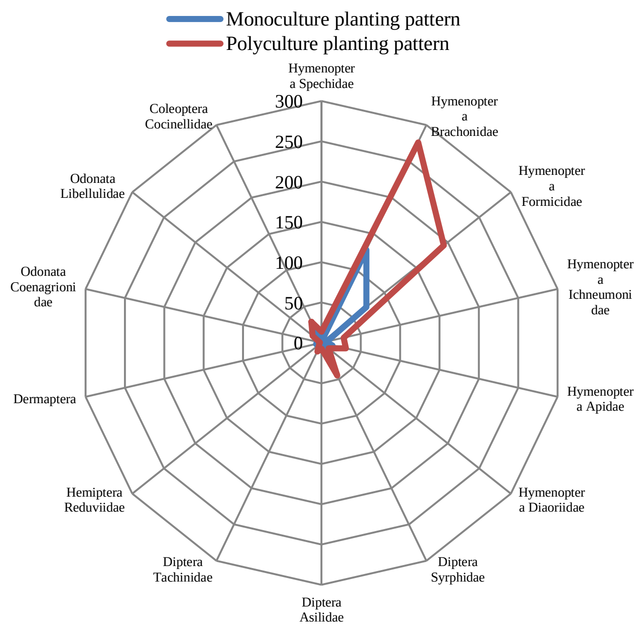

Figure 4. Abundance of natural enemies in monoculture and polyculture planting systems on coffee plantations in the Lake Toba area.

DISCUSSION

Ramos *et al*. (2020) stated that variations in mortality data indicate that the pathogenicity of entomopathogenic fungi depends on the strain of the fungus and the method of application. Entomopathogenic fungi are fungi that can cause mortality to host insects (Vajri *et al.,* 2024). The high mortality caused by Beaveria bassiana has also been tested by Chang *et al.* (2023) using the spraying method with a mortality value of 100% on the 8th day after treatment. Thi Suu *et al.* (2021) also reported that the application of B. bassiana using an autoinfection trap was able to cause CBB mortality of up to 71.3%. The application of *Beauveria* sp. using the coffee fruit immersion method has not been tested so that the effectiveness of isolates between genera cannot be compared. However, the death of CBB in coffee berries after the application of the *Metarhizium* sp. fungus is suspected to be due to the ability of the fungus to colonize coffee berries, thereby killing 100% of the CBB population in the berries. Bamisile *et al.* (2018) stated that *Metharizium* sp. and Beauveria bassiana have good prospects as pest biocontrol and are able to colonize plant tissue. Damon (2000) stated that CBB management is difficult because it is a type of frugivorous pest that lives mostly in coffee berries. The use of fungi that can colonize plant tissue is the right alternative in controlling frugivorous pests Gustianingtyas *et al.* (2021). Therefore, further research is needed regarding the colonization ability of fungi and the effectiveness of application methods for CBB in the field as an effort to conserve coffee plantations using biological agents.

The dynamics of CBB attacks on coffee berries based on the fruit maturity phase were also reported by Dufour *et al.* (2021). The dominance of symptoms in ripe coffee berries is due to the fact that ripe coffee berries have been exposed to CBB first, so the level of CBB infestation will also be higher. In addition, Indonesia, especially North Sumatra, which has a tropical climate, allows the presence of coffee berries throughout the year to encourage CBB infestation because it has a constant supply of food and habitat (Ramírez *et al.*, 2010). The Lake Toba area, which has an altitude of 1200 meters above sea level with an average temperature of 21ºC and humidity of 80%, will support the development of CBB Dufour *et al.* (2021). In addition, poor plantation management by farmers in North Sumatra due to lack of training and lack of agroecology (Dufour *et al.*, 2019) and high humidity due to lack of shade management on monoculture plantations will increase the level of pest infestation (Kuswardani *et al.*, 2023).

The high population in monoculture plantations is thought to be caused by the management of coffee plantations carried out by farmers. In monoculture plantations, farmers do not prune coffee plantations and have shade plants, namely lamtoro and gamal wood, which are not managed properly. Pruning that is not carried out causes the microenvironment to become humid and the uncontrolled CBB population will persist into the next generation (Marino *et al.*, 2015). Several studies have also reported that CBB infestation is higher in shaded coffee compared to coffee exposed to sunlight (Bosselman *et al.*, 2009; Larsen *et al.*, 2010). In addition, increasing temperatures in polyculture plantations and decreasing fruit humidity will accelerate the CBB life cycle from eggs to adults (Baker *et al.*, 1992; Jaramillo and Chabi-Olaye, 2010; Giraldo-Jaramillo *et al.*, 2018; Hamilton *et al.*, 2019). This can be seen from the development phase of CBB in polyculture planting which is dominated by the imago phase. Symptoms of attack are generally caused by female CBB imagos that have entered the copulation period. Barrera (1994) stated that female imagos invest in coffee fruit when the dry weight content of coffee beans is 20% and the endosperm is in a development stage known as semi-consistent around 120-150 days after flowering (Baker, 1999). The female imago drills holes into the coffee fruit (0.6-0.8 mm wide) (Varon *et al.*, 2004) and finally enters the seeds to lay eggs. The larvae that hatch will eat the endosperm of the fruit so that the coffee fruit cannot develop properly, and even rots and falls off (Damon, 2000; Vega *et al.*, 2014). These results are in line with research by Efrata (2019). The highest intensity of CBB attacks was found on land with monoculture planting patterns, due to the uniformity of cultivated plants, which reduces the diversity and richness of biological resources such as natural enemies. In addition, poor management of shade plants (Kuswardani *et al.*, 2023) and pruning of coffee plants that is not carried out on monoculture plantations will increase humidity in coffee plantations, thereby triggering an increase in CBB investment (Johnson *et al.*, 2020).

Conclusion: Based on the research that has been done, it is concluded that polyculture planting patterns can suppress the CBB population. In addition, two types of entomopathogenic fungi were found that have the potential to control CBB, including *Beauveria* sp. and *Metharizium* sp.

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Availability of data and material: We declare that all data is presented in this work.

Informed consent: Written informed consent was obtained from all participants regarding publishing this data.

Consent to participate: All authors participated in this research study.

Consent for publication: All authors submitted consent to publish this research article in JGIAS.

***SDGs addressed*:** Zero Hunger, Responsible Consumption and Production, Decent Work and Economic Growth

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