

Comparison of Various Control Techniques for Clove Stem Borer (*Nothopeus hemipterus*) in Samigaluh, Kulon Progo

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ABSTRACT

The clove stem borer (*Nothopeus hemipterus*) is a major pest causing significant economic losses in clove cultivation. In Samigaluh, most farmers rely on chemical pesticides for control. However, essential oils and entomopathogenic fungi offer safer and more sustainable alternatives. This study aimed to evaluate their effectiveness and determine the most suitable control method. The research was conducted in Kayugedhe Hamlet, Samigaluh, Kulon Progo, Yogyakarta, from April to September 2022. A randomized completely block design was used with different pest control treatments, including chemical pesticides (fipronil, acephate, and profenofos), botanical pesticides (10% neem oil and 10% citronella oil), biological pesticides (*Beauveria bassiana* at 1×10^8 CFU/mL), and a control. The pesticides were applied using a hydraulic pump and a wax-sealing method on larval entry holes. Larval mortality was recorded weekly for four weeks. The results showed that the application of entomopathogenic fungi (*Beauveria bassiana*) and citronella oil led to larval mortality rates of 78% and 75%, respectively, which were comparable to the effectiveness of fipronil (80%) and acephate (81%). In contrast, *N. hemipterus* larvae exhibited lower susceptibility to profenofos, with a mortality rate of only 47%, suggesting potential resistance. These findings indicate that *B. bassiana* and citronella oil extract could serve as effective and environmentally friendly alternatives for controlling the clove stem borer.

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INTRODUCTION

Clove (*Syzygium aromaticum*) has long been a vital component in Indonesian agriculture and the economy. The harvested clove flowers are a high-value export commodity in both domestic and international markets (Danthu et al., 2020). Clove is widely known for its health benefits due to its essential oil content (Otunola, 2022). Additionally, it serves as a key raw material in the cigarette

industry. Indonesia, as a major global producer, holds a strong position in the clove industry (Avianto et al., 2024; Tarore et al., 2020). However, several challenges hinder the development of the national clove industry, particularly those related to pest infestations in plantations.

The damage caused by CSB larvae results in plant death due to defoliation, which begins with symptoms of yellowing leaves on the entire plant

(Astuti & Maryani, 2016). A single tree may contain 20 to 100 borer holes, which damage both the phloem and xylem structures (Tarore et al., 2020; Widodo et al., 2020). Yield losses caused by CSB have been reported to range between 10% and 25% (Andriani et al., 2023; Rizal, 2017). Research conducted by Luanmasa et al. (2023) indicated that the intensity of clove plant damage due to CSB could reach 50.62%. Another study by Kulendeng et al. (2021) in Banggai Kepulauan Regency, found that *N. hemipterus* caused a maximum damage rate of 7.6%. According to Runaweri et al. (2017), the severity of CSB infestations varies with altitude. Damage levels at altitudes of 0–300 m, 300–600 m, and above 600 m were reported to be 12.55%, 22.88%, and 33.66%, respectively.

In the Menoreh Highlands, clove farmers primarily use acephate, fipronil, or profenofos because these pesticides are widely available and have effectively controlled pests. However, in recent years, access to these chemicals has become increasingly difficult due to supply limitations and regulatory restrictions. Additionally, the rising cost of pesticides has placed a financial burden on farmers, making it more challenging to maintain pest control measures. Given these challenges, there is an urgent need for alternative pest control solutions that are both effective and sustainable. Among various options, botanical pesticides such as citronella oil and microbial biopesticides like *Beauveria bassiana* have emerged as promising alternatives due to their unique modes of action and environmental safety (Juma et al., 2022; Sujak et al., 2020). *B. bassiana* has been widely studied for its ability to infect and kill a broad range of insect pests, but its potential against *N. hemipterus* in clove plantations remains underexplored. Similarly, while neem oil is a well-established botanical pesticide, citronella oil has received less attention despite its strong insecticidal properties, including its ability to disrupt insect neurotransmission and digestive processes (Moustafa et al., 2024).

The adoption of botanical and biological pest control methods is crucial for promoting environmentally friendly and sustainable agriculture (Riyaz et al., 2022). Unlike synthetic pesticides, these alternatives do not contribute to chemical pollution, reducing the risk of soil and water contamination. Moreover, they help maintain ecological balance by preserving beneficial organisms in the ecosystem (Amoabeng et al., 2019). These alternative pest control strategies align with integrated pest management (IPM) principles, which emphasizes a combination of preventive measures, biological control, and reduced reliance on synthetic chemicals.

Neem plants contain various biologically active compounds found primarily in their seeds and leaves. These plant parts are the main sources of pesticide production, as they contain azadirachtin, a steroid-like compound effective against hundreds of insect larvae (Shannag et al., 2015). Other active compounds in neem include salannin, nimbin, nimbolide, and various fatty acids (Benelli et al., 2017). Meanwhile, citronella oil primarily consists of geranial (46.83%), neral (34.10%), and myrcene (12.57%), along with monoterpenoids, tannins, flavonoids, and other compounds (Alves et al., 2019). According to Moustafa et al. (2021), citronella oil disrupts insect neurotransmitters, inhibits digestive enzymes, and increases oxidative stress in target pests.

The use of *B. bassiana* as a biopesticide is widely recognized for its environmental safety. The infection process begins when fungal conidia adhere to the insect cuticle, leading to interactions between the spore wall and the insect's epicuticle (Baek et al., 2022). The conidia then penetrate the insect body by producing enzymes that degrade lipids, proteins, and chitin in the cuticle. Inside the host, the fungus develops into blastospores, which destroy internal tissues within 36 to 72 hours (Islam et al., 2023). After 4 to 10 days, the infected insect dies, and the fungus forms new spores on the

cuticle surface, continuing the infection cycle (Keswani et al., 2013).

While synthetic pesticides such as acephate, fipronil, and profenofos have been commonly used to control CSB in clove plantations, recent restrictions and rising costs have made their application less feasible. Moreover, excessive reliance on these chemicals risks human health, non-target organisms, and the environment. Previous studies have explored the efficacy of various pest control methods, including neem oil (Wahedi et al., 2016), citronella oil (Rimbing et al., 2019), and *Beauveria bassiana* (Senewe et al., 2024). Still, limited research has assessed their effectiveness specifically against *N. hemipterus* infestations in clove plantations. Additionally, the extent to which these alternative methods can serve as viable replacements for synthetic pesticides remains unclear. Given these gaps, this study aims to evaluate the efficacy of botanical pesticides and entomopathogenic fungi in managing *N. hemipterus* populations, providing insights into sustainable pest control strategies for clove farmers. Additionally, it seeks to determine the most effective control technique for managing CSB infestations.

MATERIALS AND METHODS

The study was conducted in smallholder clove plantations located in Samigaluh District, Kulon Progo Regency, Yogyakarta from April to September 2022. Pesticide treatments were applied in April during the rainy season. This period was chosen because the population of clove stem borers was high, and clove trees were actively flowering. The experimental design followed a completely randomized block design (CRBD) with a single factor, which was the pest control technique. Elevation was used as a blocking factor and divided into three levels: low (0–350 meters above sea level), medium (350–700 meters above sea level), and high (>700 meters above sea level). The blocks also served as replicates, with a total of three blocks corresponding to the three elevation levels,

ensuring that each treatment was repeated three times.

Sample selection was conducted using purposive sampling. Clove trees with active stem borer holes were selected based on the presence of thick fluid and frass. Each treatment included 25 active borer holes per block. The experiment consisted of seven levels of treatments and three blocks, each serving as a replication. Every block contained a total of 175 sample holes based on the assigned treatments. Across all blocks, the total number of sample holes reached 525.

The study investigated different pest control techniques, including chemical pesticides (active ingredients: fipronil, acephate, and profenofos at a labeled dose of 2 g/L), botanical pesticides (10% neem oil and 10% citronella oil), and biological pesticides (*Beauveria bassiana* at 1×10^8 CFU/mL). A control treatment was also included. Neem and citronella pesticides were prepared by mixing 10 mL of essential oil extract with 90 mL of distilled water. Pesticides were applied using a hydraulic injection pump at a rate of 5 mL per hole. After application, holes were sealed with wax or paraffin.

After seven days, the holes were reopened. Larval mortality and active borer holes were observed weekly for four weeks. The percentage of active borer holes and pesticide effectiveness were calculated using the following formulas:

$$\begin{aligned} &\text{Percentage of Active Borer Holes (\%)} \\ &= \frac{\text{Number of Active Borer Holes}}{\text{Total Number of Treated Holes}} \times 100 \end{aligned}$$

$$\begin{aligned} &\text{Pesticide Effectiveness (\%)} \\ &= 100 - \text{Percentage of Active Borer Holes} \end{aligned}$$

After assessing pesticide effectiveness, the clove trees were maintained for six months until the flowers reached harvest maturity. Harvesting was conducted by selecting physiologically mature clove flowers. This stage was identified by the appearance of fully developed flower buds that had

not yet opened. The fresh weight of harvested clove flowers per tree was recorded. The percentage of yield loss was calculated using the following formula:

$$\text{Yield Loss (\%)} = \frac{\text{Fresh Weight of Buds per Tree (kg)}}{\text{Fresh Weight of Buds per Healthy Tree (kg)}} \times 100$$

All collected data were analyzed using analysis of variance (ANOVA) with a 5% significance level. Data analysis was conducted using R for Windows version 4.4.2 and RStudio. If a significant difference was detected between pest control techniques, a post-hoc comparison was performed using Tukey's Honestly Significant Difference (HSD) test at a 5% significance level.

RESULTS AND DISCUSSION

The results of the variance analysis on the use of active ingredients as insecticides in clove plants are presented in Table 1. The average effectiveness of chemical insecticides, such as acephate and fipronil, was not significantly different from that of biological agents, including citronella oil and *Beauveria bassiana*. This can be observed from the number of active borer holes, the percentage of active borer holes, and the effectiveness of the active ingredients. The effectiveness of the active ingredients, ranked from highest to lowest, was as follows: acephate (81%), fipronil (80%), *B. bassiana* (78%), citronella oil (75%), profenofos (49%), neem oil (20%), and the control (0%).

The effectiveness of the active ingredients was determined by the percentage of healed borer holes, which is inversely related to the percentage of active borer holes. Table 1 shows that the application of acephate left an average of 4.25 active borer holes with an active borer hole percentage of 17%. This was not significantly different from fipronil (5 holes, 20%), citronella oil (6.25 holes, 25%), and *B. bassiana* (5.5 holes, 22%). These four treatments were considered effective in controlling clove stem borers because their results

were significantly different from profenofos. The application of profenofos left 12.75 active borer holes with an active borer hole percentage of 51%.

Table 1. The effectiveness of various pesticide active ingredients on the activity of CSB larvae

Active Compound	ABH	PABH (%)	ACE (%)
Acephate	4,25 a	17 a	81 a
Fipronil	5,00 a	20 a	80 a
Profenofos	12,75 b	51 b	49 b
Neem Oil	20,00 c	80 c	20 c
Citronella Oil	6,25 a	25 a	75 a
<i>B. bassiana</i>	5,50 a	22 a	78 a
Control	25,00 d	100 d	0 d

Note: ABH = number of active borer holes; PABH = percentage of active borer holes; ACE = active compound effectivity. The displayed values represent the mean. The same notation indicates a significant difference based on Tukey's HSD test ($\alpha = 5\%$).

Below profenofos, neem oil showed a significantly higher number of active borer holes, with an average of 20 holes and an active borer hole percentage of 80%. All treatments differed significantly from the control, where all samples still had active borer holes with a percentage of 100%. The effectiveness of profenofos and neem oil was 49% and 20%, respectively. This indicates that profenofos and neem oil were less effective in suppressing or eliminating clove stem borers. Profenofos has been widely used by clove farmers in the Menoreh Highlands for a long time. This suggests that *N. hemipterus* has developed resistance to this active ingredient, as reflected in its low effectiveness (Table 1).

Resistance of borers to insecticides is an important factor in determining the effectiveness of active ingredients. The high effectiveness of chemical insecticides, such as acephate and fipronil, as well as biological agents, such as

citronella oil and *Beauveria bassiana*, may be due to their first-time application in clove plantations in the Menoreh Highlands. This suggests that clove stem borers have not yet developed resistance to these active ingredients. In contrast, the low effectiveness of the chemical insecticide profenofos and the biological agent neem oil is likely due to repeated applications by clove farmers. This repeated use may have led to resistance in clove stem borers against these active ingredients.

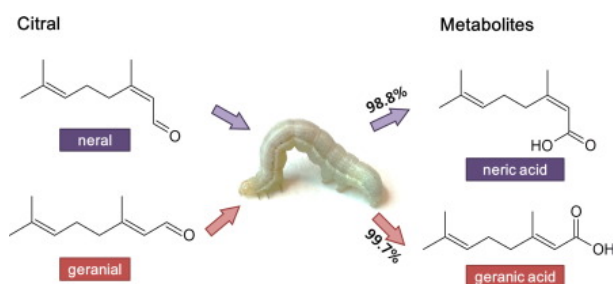


Figure 1. Chemical structure of the main components in citronella oil (Neral and Geranial), which produce metabolites in the form of neric acid and geranic acid (Tak & Isman, 2016).

Repeated exposure to the same active ingredients can cause resistance in clove stem borers. Resistance develops when CSBs survive treatment and pass their traits to the next generation. Over time, the next generation inherit this ability, and becomes harder to control (Xu et al., 2024). One common mechanism is metabolic resistance. Insects produce more enzymes that break down the active ingredients before they take effect (Zhao et al., 2021). Another mechanism is target site resistance. Changes occur in the insect's nervous system or other biological targets, making the pesticide less effective (Boaventura et al., 2020; Wani et al., 2022).

The active ingredients *Beauveria bassiana* and citronella leaf extract have the potential to serve as alternative pesticides to replace chemical insecticides such as acephate and fipronil. These biological agents leave a similar number of active

borer holes, percentage of infestation, and effectiveness based on statistical analysis. A study by Tumewan et al. (2020) reported that the application of *B. bassiana* using the root infusion method achieved an effectiveness of 75.59% in controlling *Hypsipyla semivelutina*. Another study by Tarore et al. (2020) demonstrated that *B. bassiana* reduced *H. semivelutina* larval infestations by 10% at a concentration of 10^8 CFU/mL and by 15% at 10^{10} CFU/mL. Research on cocoa pod borers also found that *B. bassiana* could decrease infestation levels from 95.71% to 80% (Fiana et al., 2015). Several other pests can also be controlled using *B. bassiana*. These include the sugarcane stem borer (Mejía et al., 2020), the coffee stem borer (Manikandan et al., 2019), *Xystrocera festiva* in acacia stems (Thu et al., 2021), and the pepper stem borer *Lophobaris piperis* (Wiratno et al., 2020). *B. bassiana* has also been reported to control many other insect pests.

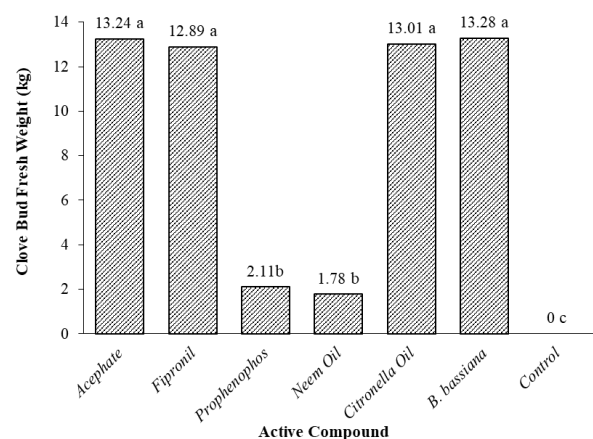


Figure 2. Clove bud fresh weight per tree under various active compounds of pesticide.

The fungus *Beauveria bassiana* has the potential to be developed as a biopesticide for controlling clove stem borers. It thrives in high humidity, which can be maintained by sealing borer holes with wax or plasticine after application (Dannon et al., 2020). This method creates an optimal environment for fungal growth. Once *B. bassiana* penetrates the epicuticle of CSB larvae, it forms blastospores at the tip of the appressorium

or haustorium before breaking through the insect's cuticle. The blastospores then produce lethal toxins such as oosporeine, tenelline, bassianine, and beauvericine (Ávila-Hernández et al., 2022). These toxins circulate in the larval hemolymph, increasing blood pH and disrupting neural function. As a result, the larvae experience paralysis, tremors, reduced appetite, lethargy, and eventual death (Altinok et al., 2019).

Besides being effective, these alternatives must also be practical for farmers. *Beauveria bassiana* is easy to apply. However, it works best in specific environmental conditions, such as high humidity and suitable temperatures. Citronella oil is natural and biodegradable. However, it needs frequent reapplication to keep its insecticidal effects. In terms of cost, both options can be cheaper over time, especially if farmers produce them locally. Large-scale use may still need improvements in formulation and application methods. These adjustments can help make them more efficient and easier to use.

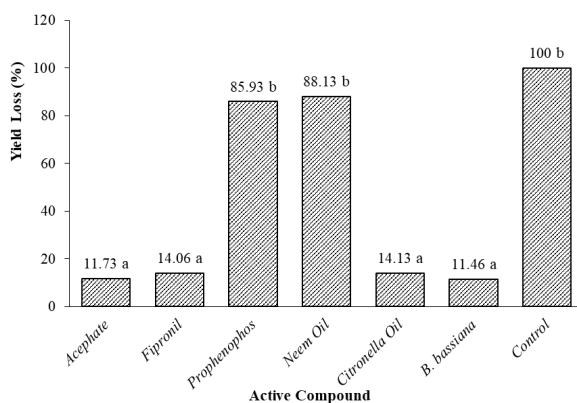


Figure 3. Yield loss of clove tree under various active compounds of pesticide.

Essential oils not only act as insect repellents but also function as contact pesticides and fumigants for certain insect species (Scalvenzi et al., 2024). Botanical pesticides are expected to provide effective, efficient, and environmentally safe pest control for clove plants. Citronella oil contains key active compounds, including geranial

(46.83%), neral (34.10%), and myrcene (12.57%), along with monoterpenoids, tannins, and flavonoids (Alves et al., 2019). According to Moustafa et al. (2021), citronella oil disrupts neurotransmitters, inhibits digestive enzyme activity, and increases oxidative stress in target insects. Rizal (2017) reported that applying citronella oil pesticide to CSB borer holes resulted in an 88.33% larval mortality rate. The high volatility of pure citronella oil likely produces a fumigation effect that is lethal to larvae. A study by Abdel-Hakim et al. (2021) found that citronella oil extract caused larval diapause in *Sesamia cretica* due to a reduction in total carbohydrate content. Research on rice crops has also shown that citronella-based pesticides can suppress populations of brown planthoppers, armyworms, and rice stink bugs (Telaumbanua et al., 2021).

Effective control of CSB allows clove plants to achieve optimal production. In contrast, ineffective pest control results in yield loss. Figure 2 presents data on production. Harvesting was conducted six months after applying CSB pesticide treatments. During this period, active larvae continued boring into the stems and damaged the xylem and phloem vessels. This hindered water, nutrients, and assimilate transport. Ultimately it affected both vegetative growth and generative development, including flower formation.

Figure 2 shows that the highest flower production was obtained from clove trees treated with pesticides containing the active ingredients acephate (13.24 kg/tree), fipronil (12.89 kg/tree), citronella oil (13.01 kg/tree), and *Beauveria bassiana* (13.28 kg/tree). These four treatments showed no significant differences from one another but differed significantly from treatments using profenofos (2.11 kg/tree), neem oil (1.78 kg/tree), and the untreated control (0 kg/tree).

Yield loss was calculated by comparing the production of treated plants with healthy clove trees. The average production of healthy plants

was 15 kg of fresh flowers per tree. Figure 3 indicates that untreated control plants produced no flowers, resulting in a 100% yield loss. Trees treated with neem oil and profenofos experienced yield losses of 88.13% and 85.93%, respectively. These results were significantly different from those of more effective pesticides, including acephate (11.73%), fipronil (14.06%), citronella oil (14.13%), and *B. bassiana* (11.46%). Overall, botanical pesticides such as citronella essential oil and entomopathogenic fungi such as *B. bassiana* show potential as alternative pesticides for controlling *N. hemipterus*.

CONCLUSIONS

1. The entomopathogenic fungus *Beauveria bassiana* and citronella essential oil have the potential to serve as alternative pesticides for controlling the clove stem borer (*Nothopeus hemipterus*). Both treatments demonstrate high effectiveness in reducing the number and percentage of active boring holes.
2. Clove plants treated with these active ingredients show comparable production levels and lower yield losses, similar to those treated with chemical pesticides.

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