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SHORT COMMUNICATION

The efficacy of botanical pesticides in controlling coffee berry borer, *Hypothenemus hampei* (Ferrari, 1867) (Coleoptera: Curculionidae): A meta-analysis

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ABSTRACT

Coffee berry borer pest (CBB) is one of the main pests that has a significant impact on coffee production and quality. In Indonesia, the utilization of plant-based pesticides has promising prospects in controlling CBB. The purpose of this study is to provide information on the impact of different types of plant pesticide on CBB mortality through a measurable algorithm analysis. A literature search was performed using Scopus, Web of Science, Google Scholar, Researchgate, and ScienceDirect. A linear mixed model (LMM) was applied to evaluate the effect of botanical pesticide application on the mortality rate of CBB. A total of 14 plant families were included in meta-regression analysis for estimating the effect size of each family. The average effect of pesticide exposure to CBB analyzed using LMM was 0.039 which mean that botanical pesticidal exposure has significant effect on the mortality rate of CBB ($P<0.05$). The results of this study suggested that the use of botanical insecticide especially derived from plants belonging to Family Anacardiaceae was significantly effective in controlling CBB.

Key words: coffee berry borer, plant-based pesticide, pest control.

INTRODUCTION

Coffee is one of the agricultural commodities that significantly contributes to the country's economy. According to the Central Statistics Agency, the freight-on-board (FOB) value of coffee exports in Indonesia amounted to $858.558 million with a total export of 387.26 thousand tons in 2021. In the same year, coffee production in Indonesia reached 786.2 thousand tons, with the largest contributor being smallholder plantations producing 780.9 thousand tons of coffee (99.32%) (Sub Directorate of Estate Crops Statistics, 2022). The growth of coffee production is directly proportional to the increase in the area of coffee plantations, which rose by 30,600 ha or 2.49% compared to the previous year. According to the Sub Directorate of Estate Crops Statistics (2022), Indonesia coffee production in 2021 reached 817 kg/ha, with a total plantation area of 1,278.8 thousand hectares. However, damages caused by pest has a significant impact on coffee production and quality.

Several insect pests have been reported in coffee, with the most important ones being the coffee leaf miner, the coffee berry borer, and the coffee stem borers. Infestation by the coffee berry borer insect (*Hypothenemus hampei*) infestation can damage the crop, reduce the weight of coffee berries, cause rot, and lead to imperfect development of coffee plants, resulting in losses for coffee farmers (Suswati et al., 2020). The coffee berry borer pest (CBB) proliferates rapidly in poorly maintained farms, causing damage such as premature fruit drops and a loss of both quantity and quality in the yield (Muliasari et al., 2016). The CBB directly affects the harvest by burrowing into coffee berries, laying eggs, living inside them, and consuming the coffee beans (Erfan et al., 2019).

Integrated pest management strategies should be implemented to reduce or control pest infestations in coffee plant populations. The use of pesticides is one common control technique employed by farmers. Synthetic pesticides have a rapid insecticidal effect. However, their use is not recommended due to the potential for extensive negative impacts. The intensive

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use of synthetic chemical pesticides can lead to ecosystem damage in agricultural land, soil residue contamination, pest resistance to pesticides, and the exposure of farmers and consumers to pesticide residues (Wiratno et al., 2013).

Nowadays, the use of synthetic chemical pesticides needs to be avoided as much as possible, and coffee farmers as well as agricultural practitioners are adopting more environmentally friendly methods, such as using biological control (Apriyanto & Nadrawati, 2019; Wagiyana et al., 2019), as well as the application of biopesticides (plant-based pesticides and microbial pesticides) (Sutriadi et al., 2019). Marrone (2019) stated that biopesticides are organic compounds and antagonistic microorganisms that inhibit or kill plant pests and diseases. Plant-based pesticides consist of single or multiple active ingredients derived from plants and can be used to control plant pests.

However, the effectiveness of plant-based pesticides is lower than chemical pesticides, requiring more frequent application. The active ingredients in plant-based pesticide were degraded quicker, making them unsuitable for long-term storage (Sutriadi et al., 2019). Therefore, farmers prefer the use of chemical pesticides. Plant-based pesticides have preventive characteristics suitable for use before pest infestations occur. Despite their limitations, plant-based pesticides offer advantages such as quickly inhibiting insect feeding behavior, thus reducing plant damage, having a broad control spectrum, being effective against pests resistant to synthetic insecticides, and having relatively low toxicity mammals, making them safe for life (Wiratno et al., 2013).

The utilization of plant-based pesticides worldwide, especially in Indonesia, holds promising to prospects. The relatively easy processing, low requirement for advanced technology, and abundant raw materials in nature support this. A previous study (Reyes et al., 2019) stated that a pesticide derived from *Eucalyptus resinefer* leaf extract (an endemic flora of eastern Australia) can have a mortality effect of up to 90.00% against CBB. Similarly, the leaf extract of *Tephrosia purpurea*, a plant in the legume family that grows in warm climates worldwide, has a mortality effect of up to 96.00% on CBB (Zorzetti et al., 2012). Several plants that grow and are cultivated in Indonesia have been utilized as raw materials for plant-based pesticides. Neem leaf extract provides a mortality effect on CBB of up to 44.00%, while Moringa tree seed extract reaches 62.00% (Zorzetti et al., 2012). On the other hand, garlic extract reaches 50.00% (Reyes et al., 2019) and castor leaf extract reaches 53.70% (Celestino & Pratissoli, 2015).

Research on the use of plant extracts as raw materials for pesticides against CBB has been extensively conducted globally, with varying effectiveness observed for each formulation. The purpose of this paper is to provide information on the impact of different types of plant-based pesticides on CBB mortality through a measurable algorithm analysis.

MATERIALS AND METHODS

Data Collection and Selection. Data selection and literature search were carried out following the method by Copes & Ojiambo (2021). The first stage was a digital literature search. A literature search was performed using Scopus, Web of Science, Google Scholar, ResearchGate, and ScienceDirect. The keywords used were: Botanical pesticides, coffee berry borer (CBB), coffee berry borer pest attacks, coffee berry borer mortality, and coffee. A reference search was also carried out from the literature found to find additional relevant literature. This literature search was conducted from November 2022 to April 2023.

The literature was then filtered and selected to make the meta-analysis process more accurate. Firstly, literature whose research did not pertain to the CBB mortality in the application of botanical pesticides and research using mixed pesticides (a combination of vegetable and chemical) were excluded because they were not in accordance with the objectives of the meta-analysis. Literature whose research was carried out outside the laboratory scale was excluded. This is because the literature obtained is global in nature, with field conditions that are too varied, and it is feared that it will affect the yield of botanical pesticides. After that, the literature that does not have complete data (concentration, time of application) was excluded. The data screening process was visualized in Figure 1.

Modelling and Statistical Analysis. The modelling aimed to analysed the effect of specified parameters on mortality rate of coffee berry borer. In this study, we used R software version 4.3.0 with supporting libraries including *nlme* and *sjstats*. A linear mixed model (LMM) was applied to evaluate the effect of botanical pesticide application on the mortality rate of coffee berry borer. The level of botanical pesticide application was considered a fixed factor, and differences across studies were considered a random factor (Sholikin et al., 2020). The LMM equation for modelling the metadata is:

$$Y_{ij} = B_0 + B_1 X_{ij} + S_i + e_{ij}$$

Y_{ij} = Mortality rate;
X_{ij} = Botanical pesticide concentration;
S_i = Study;
e_{ij} = Residual error.

The model was then tested for significance determination using analysis of variance (ANOVA). Data with a P-value of 0.05 or less were considered a significant result, and a level of $0.05 < \text{P-value} < 0.1$ was considered a tendency towards an effective result (Handayani et al., 2023).

Effect Size. The effect size of the botanical pesticide towards the mortality rate of CBB was calculated by inspecting individual standardized mean difference (SMD) for each study comparison, utilized as the outcome, and the associated standard error (SE) as the measure of variance in meta-regression analysis. Even if a preliminary overall test for heterogeneity is nonsignificant, meta-regression can be performed to investigate the causes of heterogeneity (Higgins & Thompson, 2002). The calculation of the effect size was done by grouping the plant based on their family and analyzed the SMD for each group using R Development Core, Vienna, Austria, version 3.5.1. The packages "meta", "metafor," and "stats" were used for all analyses.

RESULTS AND DISCUSSION

In total, 121 literatures and abstracts were found from all databases. After selection, 17 studies were used for meta-analysis. From these 17 studies, 133 comparisons for mortality rate of CBB from 14 different plant families were represented. The plant families that have botanical pesticide potential included in this study were Anacardiaceae (Santos et al., 2013), Apocynaceae (Zorzetti et al., 2012), Arecaceae (Indriati & Samsudin, 2018; Indriati et al., 2021), Euphorbiaceae (Celestino et al., 2016), Fabaceae (Zorzetti et al., 2012), Hypercaceae (Soares et al., 2022), Lamiaceae (Mawussi et al., 2009; Mendesil et al., 2011; Santos et al., 2022), Meliaceae (Zorzetti et al., 2012), Moringaceae (Zorzetti et al., 2012), Myrtaceae (Reyes et al., 2019), Piperaceae (Santos et al., 2010; Santos et al., 2011; Soares et al., 2022), Poaceae (Soares et al., 2022), Rutaceae (Brito et al., 2021), and Urticaceae (Soares et al. 2022).

The average effect of pesticide exposure on mortality rate of CBB, analyzed using the linear mixed model (LMM), was 0.039, meaning botanical pesticide have a significant effect on the mortality rate of CBB ($P< 0.05$; Table 1). It suggested that botanical pesticides originating from different plant sources show a possitive effect on the mortality rate of CBB. This study was consistent with previous study conducted in Java (Manson et al., 2022) and Brazil (Brito et al., 2021).

A total of 14 plant families were included in the meta-regression analysis for estimating the effect size of each family (Table S1). Across all studies, botanical pesticides caused significant mortality of adult CBB (Figure 2). The highest effect on the mortality rate of CBB was observed for botanical pesticides derived from Anacardiaceae (10.95), Arecaceae (5.08), and Lamiaceae (2.39) (Figure 2).

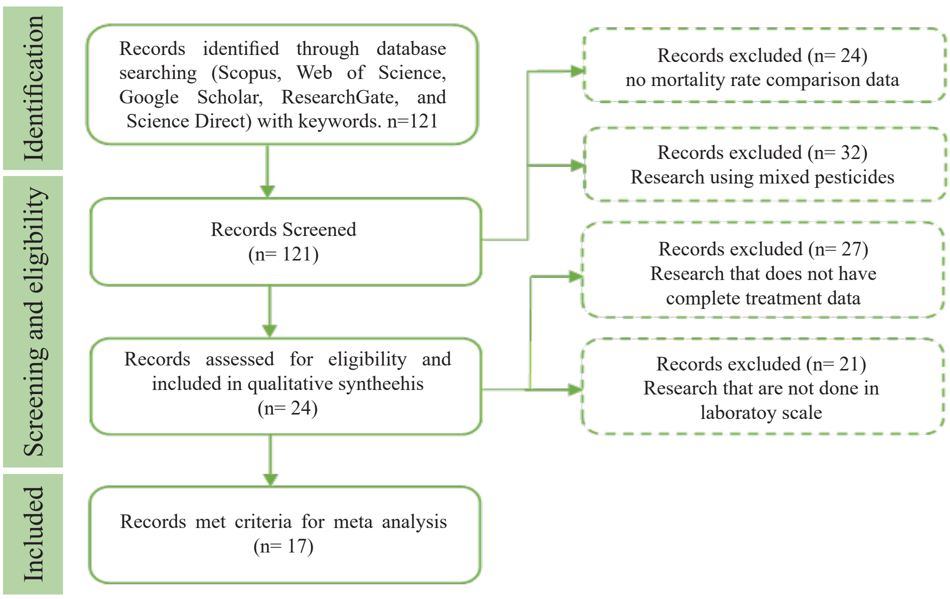

Figure 1. Flowchart diagram describing the data screening process of literature/records for subsequent meta-analyses.

Table 1. The result of statistical analysis using linear mixed model of botanical pesticide on mortality rate of CBB

Parameter	n	Parameter estimates			Model estimates		
		Intercept	SE intercept	Slope	SE Slope	P-Value	R-Seq
Mortality Rate	133	31494.836	6598.021	168.998	80.577	0.0395	0.847

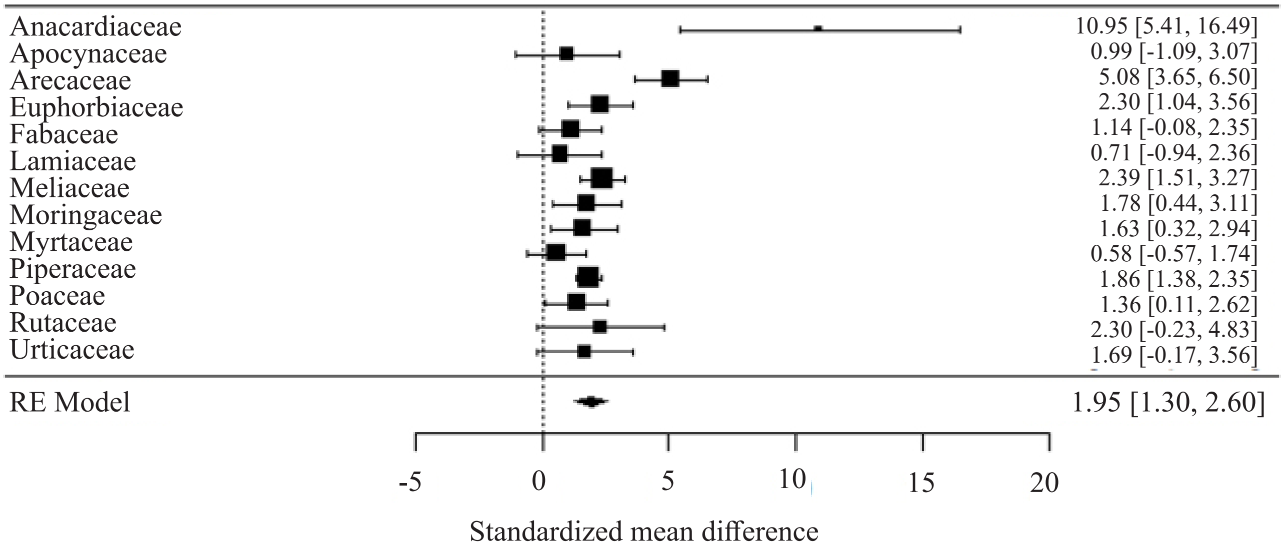

Figure 2. Forest plot pf the effect size or standardized mean difference (SMD) of the effect of botanical pesticide on mortality rate of CBB. The vertical lines represent a mean difference of 0 or no effect. Each square reflects the relative weighting of the study to the overall effect size estimate.

The effects of botanical pesticides on CBB in a lab setting are systematically analyzed in this article. Overall, we discovered that adult mortality was negatively impacted by botanical pesticides. In the present meta-analysis, we observed that overall botanical pesticides have significant effect in the mortality rate of CBB. However, the highest effect was obtained when the adult CBB was exposed to the extract of *Schinus terebinthifolia* member of Anacardiaceae family.

The *S. terebinthifolia* has a high content of anacardic acid (Umehara et al., 2020) and cardanol (Stahl et al., 1983), which exhibit insecticidal activity against *H. hampei*. These compounds can disrupt the insect's physiology, leading to mortality or decreased reproductive capacity (Belhoussaine et al., 2022). Previous studies also showed that *S. terebinthifolia* can act as repellents for some insect. The essential oil from *S. terebinthifolia* contain germacrene D (25.0%), (E)-β-cariophyllene (17.5%) and δ-elemene (10.5%) (Cole et al., 2013), which work as insect repellents (Noriega et al., 2019).

S. terebinthifolia ethanolic extract has also proven to be an effective antifeedant for insect (Couto et al., 2020). Insect feeding inhibitors act by activating specific inhibitory receptors or by disrupting the normal operation of neurons that detect phagostimulating substances (Koul, 2008). Feeding inhibitors have many advantages, as they can preserve particular crops while preventing harm to non-target creatures. Compounds that diminish pest injury by making plants unappealing or unpalatable can be considered viable alternatives to traditional pesticides since insect damage to plants arises from feeding or from the spread of infections during feeding (Koul, 2008).

The second most effective in controlling CBB is from the Arecacea family, represented in this study by coconut shell wood vinegar. Formaldehyde, which has a carbonyl (C=O) group resembling that of carbamate, is present in the wood vinegar. According to Wititsiri (2011), the carbamate might disrupt an insect's nervous system and render it inert. Additionally, the insecticidal action of the wood vinegar should be aided by the acetic acid, which makes up more than 50% of it (Yatagai et al., 2002).

The coffee berry borer was affected by the essential oils isolated from specific Lamiaceae plants in both an insecticidal and repelling manner, demonstrating their potential as natural substitutes for manufactured chemical insecticides (Reyes et al., 2019). Essential oils from the Lamiaceae family may harm coffee berry borers directly or indirectly by interfering with their ability to reproduce, alter their feeding habits, or both. Furthermore, some Lamiaceae plants include substances with repellent qualities that can help keep pests away from coffee plants (Mendesil et al., 2011). Although Lamiaceae plants and their essential oils have showed promise in preventing the coffee berry borer, more research is necessary to determine how best to use them in actual coffee estates. Their efficiency may vary depending on the specific Lamiaceae species, the application technique, and the surrounding environment.

It's critical to ensure proper application and adherence to sustainable and ecologically friendly techniques when considering any pest control strategy, including the use of natural products like essential oils from the Lamiaceae family. The most efficient and environmentally friendly way to control coffee berry borer infestations while avoiding negative effects on the environment is to use integrated pest management (IPM) tactics, which combine different pest control techniques.

CONCLUSION

The use of botanical pesticide was significantly effective in controlling CBB. Among the 14 plant families commonly used as botanical pesticide, the Anacardiaceae family has the highest effect size in the mortality rate of CBB.

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AUTHORS' CONTRIBUTIONS

SK, RTA and AA were contributed in collecting data, analyzing data, as well as preparing the manuscript. EA and PL were contributed in preparing and finalizing the manuscript.

COMPETING INTEREST

The authors declare that they have no conflict of interest.

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