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EXPLORING THE REPELLENT AND INSECTICIDAL EFFECTS OF BLACK PEPPER (*Piper nigrum* L.) AGAINST SAWTOOTHED GRAIN BEETLE (*Oryzaephilus surinamensis* L.)

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ABSTRACT

Oryzaephilus surinamensis, also known as the sawtoothed grain beetle, is a widely distributed storage pest that thrives in products with high sugar and carbohydrate contents. Every year, *O. surinamensis* causes devastating losses in post-harvest and stored products, particularly grain products. The aim of this study was to determined the repellence and toxicity actions of black pepper (*Piper nigrum*) against *O. surinamensis*. The repellence bioassay was conducted using two types of treatments, hot infusion of black pepper powder at concentrations of 25, 50, 75 and 100 g/L and commercial black pepper oil at 1.25, 2.50, 3.75, and 5.00 mL/L. A toxicity bioassay through contact was also investigated using commercial black pepper oil at the same concentrations. The highest repellence action was recorded at 25 g/L (5.70±1.055) for hot infusion and at 2.50 mL/L (5.40±0.400) for commercial black pepper oil. Meanwhile, in the toxicity bioassay, mortality was recorded to reach 50% after 6 hours and 24 hours of exposure at 3.75 mL/L and 2.50 mL/L concentrations, respectively. The highest mortality was recorded at 3.75 mL/L (20.75±1.315) and reached 83% after 48 hours of exposure. Thus, it can be said that black pepper, despite being prepared in the simplest way possible for use in the home, is a potent insect deterrent and excellent biopesticide against the sawtoothed grain beetle.

Keywords: *Oryzaephilus surinamensis*, *Piper nigrum*, stored product, biocontrol, sustainable

ABSTRAK

Oryzaephilus surinamensis, juga dikenali sebagai Kumbang Bijirin Bergigi Gergaji merupakan serangga perosak makanan simpanan yang tersebar secara meluas dan membiak dengan mudah dalam produk yang mempunyai kandungan gula dan karbohidrat yang tinggi. Setiap tahun, *O. surinamensis* menyebabkan kerugian besar terhadap hasil tuaian dan stok simpanan makanan terutama produk bijirin. Tujuan kajian ini adalah untuk menentukan tindakan penolakan dan ketoksikan lada hitam (*Piper nigrum*) terhadap *O. surinamensis*. Bioassai penolakan dijalankan menggunakan dua jenis rawatan, infusi panas serbuk lada hitam pada kepekatan 25, 50, 75 dan 100 g/L dan minyak lada hitam komersial pada 1.25, 2.50, 3.75, dan 5.00 mL/L. Bioassai ketoksikan melalui sentuhan juga diuji dengan menggunakan minyak lada hitam komersial pada kepekatan yang sama. Penolakan tertinggi dicatat pada kepekatan 25g/L (5.70±1.055) untuk rawatan infusi panas serbuk lada hitam dan pada 2.50 mL/L (5.40±0.400) untuk minyak lada hitam komersial. Sementara itu, dalam bioassai ketoksikan, kematian direkodkan mencapai 50% selepas 6 jam dan 24 jam pendedahan pada kepekatan 3.75 mL/L dan 2.50 mL/L, masing-masing. Kematian tertinggi dicatatkan pada kepekatan 3.75 mL/L (20.75±1.315) dan mencapai 83% kematian selepas 48 jam pendedahan. Oleh itu, boleh dikatakan bahawa lada hitam, walaupun disediakan dengan cara yang paling mudah untuk digunakan di rumah, adalah penghalau serangga yang kuat dan biopestisid yang sangat baik terhadap kumbang bijirin.

Katakunci: *Oryzaephilus surinamensis*, *Piper nigrum*, produk simpanan, biokawalan, mampan

INTRODUCTION

Oryzaephilus surinamensis (L.), also known as the sawtoothed grain beetle, is a serious storage and dominant pest from the family Silvanidae in the order Coleoptera (Nurul Huda & Noor Amni 2020). The beetle is described as small, flattish, and brown to dark red in colour, often found at the bottom layer of infested food products (Nurul Huda & Noor Amni 2019). The sawtoothed grain beetle is nearly identical with the merchant grain beetle, *Oryzaephilus mercator* (Fauvel) however, they can be distinguished by the presence of six tooth-like projections on the prothorax of *O. surinamensis*. Another distinctive feature is that *O. surinamensis* is unable to fly, while *O. mercator* able to fly.

Oryzaephilus surinamensis is known to be a storage pest during its larval and adult stages due to its dietary consumption of high-carbohydrate foods. Storage pests are estimated to cause 5% to 10% losses of post-harvested food products and sawtoothed grain beetles in particular, are responsible for more than 6% of this loss (Fox 2013; Garcia et al. 2017). In Malaysia, *O. surinamensis* is a serious threat compared to other storage pest such as *Tribolium castaneum, Sitophilus oryzae* and *Cadra cautella* (Syarifah Zulaikha et al. 2018). The beetle is also known as a secondary pest that infests grains with a history of previous infestation by other insect pests or broken kernels damaged during mechanical transport. *Oryzaephilus surinamensis* has a wide distribution and is considered cosmopolitan. They can be found in various habitats such as mills, fodder storage, shops, and warehouses. This can be attributed to the species' high fertility and mobility, as well as its adaptability to extreme temperatures and humidity. The flat and slender quality that the grain beetle's anatomy has is the key to its successful infestation of packaged food by crawling into small holes of the package guided by food odour (Mowery et al. 2004; Nurul Huda & Noor Amni 2020). They live in the lower layer of the infested food product and are thus difficult to detect (Kłyś & Przystupińska 2015).

The threat that *O. surinamensis* poses to post-harvest food products is decreased nutrient value and aesthetic value. Moreover, insect infestation can increase the heat and moisture content of food storage, which is a suitable environment for microbial growth (Kiran & Prakash 2015) such as fungi and bacteria. *Oryzaephilus surinamensis* can also act as a vector for a toxigenic fungus such as *Aspergillus* spp. by dispersing the spores. Besides, waste products from *O. surinamensis* such as bodies, eggs, faeces, and secretions, may cause allergic reactions in some people (Kłyś et al. 2017).

The current management of this sawtoothed grain beetle infestation is through the application of fumigants or chemical insecticides such as phosphine. However, the use of phosphine has a few disadvantages, such as its high mammalian toxicity and persistence in nature. Up until now, there has been no in-home pesticide treatment completely safe for humans other than good storage hygiene with the purpose of preventing the spread of *O. surinamensis* infestation. In contrast, plant-derived pesticides possess biological properties such as rapid breakdown and are non-toxic, lowering the risk to the environment and non-target organisms. In recent studies on biopesticides, some plants that have insecticidal properties and repellent action against *O. surinamensis,* such as allspice (*Pimenta dioica),* garlic (*Allium sativum),* brown mallet (*Eucalyptus astringens),* and black pepper (*Piper nigrum*) have shown potential in repelling *O. surinamensis* as essential oils and powders (Kłyś & Przystupińska 2015; Wagan et al. 2019). Repellence is defined as a phenomenon that inhibits pest's ability to track, locate and/or identify its host.

This research also has similar aims, which were to determined the insecticidal and repellent activity of black pepper (*Piper nigrum*) against *O. surinamensis* and identify the suitable concentration and exposure time for the maximum effect. Results this research could provide more insight on potential user-friendly and sustainable strategies for dealing with *O. surinamensis* infestations in the house.

MATERIALS AND METHODS

Insect Culture

Oryzaephilus surinamensis was reared in several 800 ml plastic containers (pet bottles) under laboratory conditions (27ºC and 64% RH). A hundred grams of oat groats were used as the food for mass rearing. The containers were opened once per week to allow oxygen penetration. Insects were kept in the culture and allowed to breed and establish until further use. Regular hygiene monitoring was also done on the insect culture so that no growth of fungi occurs in the culture. Fungus infested culture was discarded, and new cultures was prepared if infestation occur in the culture or the culture medium.

Preparation of Treatment

The treatment was prepared using a modified method of Shah and Shahjahan (2006). The locally brought black pepper seeds were ground into powder and made into a solution by mixing them with 100 mL boiling water. The mixture was stirred and left to stand for the next 24 hours. The mixture was filtered through a fine cloth. The solutions with the concentrations of 25, 50, 75 and 100 g/L were prepared. Meanwhile, the black pepper oil was diluted based on the number of drops (1 drop ≈ 0.05mL); 2.5, 5, 7.5 and 10 drops per 100 mL of water were prepared to get concentrations of 1.25, 2.50, 3.75 and 5.0 mL/L. One drop of glycerine was also added as an emulsifier to temporarily break down the oil into tiny droplets in the dilution.

Repellence Bioassay

The repellence action of black pepper hot infusion and oil against the adults of *O. surinamensis* (random sexes) was determined using a modified method of Kłyś et al. (2017). In this method, a filter paper was cut into halves with one half treated with a hot black pepper infusion and the other half treated with distilled water as a control (Figure 1). The treated filter papers were allowed to dry and placed in a petri dish. A total of 25 adult beetles were placed at the centre of the petri dish with 2g of food (oat groat). The mouth of the petri dish was wiped with cooking oil to prevent insect escape, capped, and sealed with parafilm. Then, the petri dish was placed in the insect cage to prevent pest infestation from the outside environment. The procedure was repeated with dilutions of black pepper oil. Table 1 shows the list of treatments for the repellence bioassay. The experiment was conducted in five replications. After 24 hours, the number of insects on the treated filter paper and control filter paper were counted, and the repellent index was calculated using Liu et al. (2013) formula:

$$PR= \frac{C-T}{C+T} \times 100$$

Where,
PR is the percent repellence of *O. surinamensis,*
T is the number of adult *O. surinamensis* in the treatment area,
C is the number of *O. surinamensis* in the control area.

Table 1. List of treatments with hot infusion and oil dilution for repellence bioassay

Hot Infusion g/L	Oil Dilution mL/L
25	1.25
50	2.50
75	3.75
100	5.00

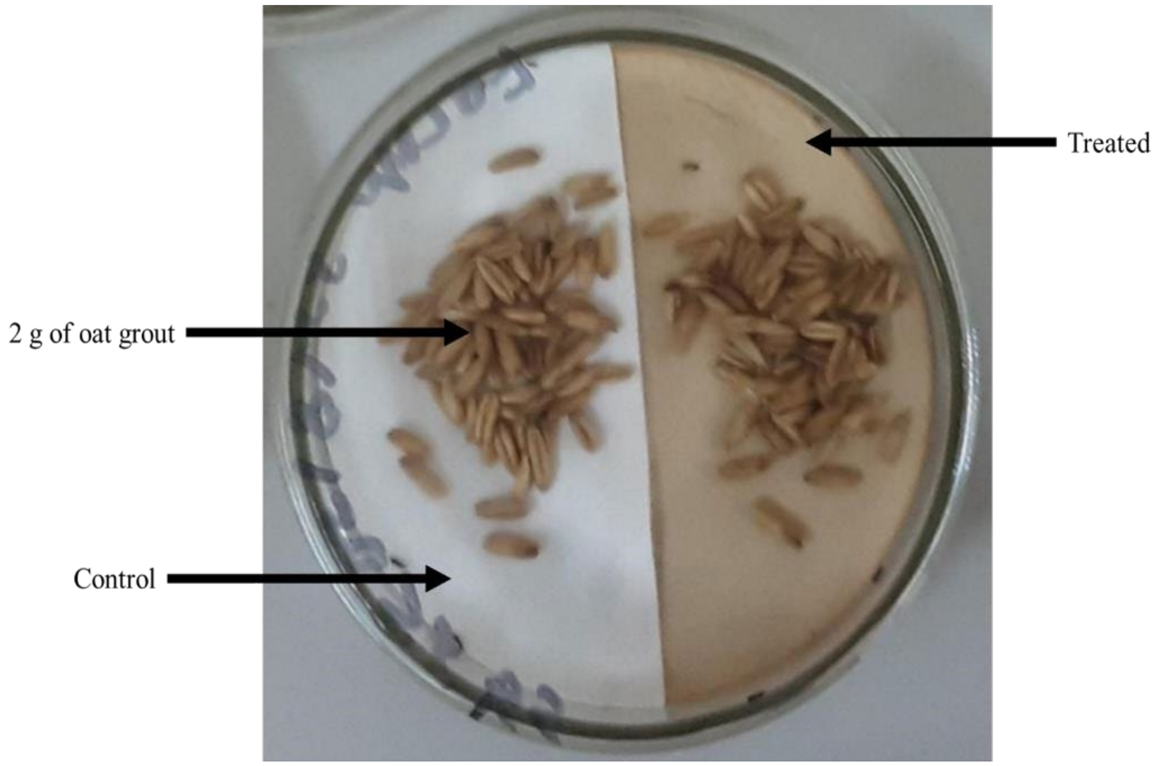

Figure 1. Repellence bioassay consisting of two halves, control side and treated side with 2 g of oat grout

Toxicity Bioassay
The toxicity bioassay was performed using commercial black pepper oil dilutions only. This experiment was conducted with the justification that commercial black pepper oil is purely etracted compared to crude extract made through a hot infusion process. The insecticidal action

of black pepper oil against 25 individuals of *O. surinamensis* was determined by calculating the mortality of adult beetles. In this experiment, 25 adults were sieved and put into a petri dish with filter paper. A dilution of black paper oil (similar concentrations as mentioned in Table 1) was sprayed once directly on the insects. The distance between the filter paper and the spray bottle was set at 15 cm. This is the best application distance to fully coat the insect with treatment and at the same time, prevent insects from drowning and causing an error in the calculation. The volume sprayed for each application was estimated at around 2.1 mL. The petri dishes were sealed with tape. Insect mortality at different times of exposure was determined at 30 minutes, 1 hour, 6 hours, 24 hours, and 48 hours. Experiments were repeated with three replications. The mortality of *O. surinamensis* was calculated using Abbott (1925) formula:

$$PT = \frac{T - C}{100 - C} \times 100$$

Where,
PT is the percent mortality of *O. surinamensis*,
T is the number of *O. surinamensis* killed in the treatment,
C is the number of *O. surinamensis* killed in control.

Statistical Analyses
The data from this experiment were analysed using IBM SPSS for Windows®. The data for the repellence bioassay did not meet the normality assumption for a parametric test, so it was subjected to the Kruskal-Wallis H-Test followed by multiple means comparison using the Mann-Whitney U test. However, the data for the toxicity bioassay was found to be normally distributed and variance based on the mean is homogenous at $P>0.05$, therefore, it was subjected to parametric tests. Differences in insect number and mortality were used to determine the effectiveness of black pepper as a repellent or bioinsecticide in controlling the infestation of sawtoothed grain beetles in household applications. Relationships between concentration and time of exposure were examined using an analysis of variance (ANOVA). Multiple mean comparisons were conducted using a post-hoc test of Tukey's HSD when significant differences were detected in an ANOVA test. Probit Analysis was used to determine the LC_{50} for the toxicity bioassay

RESULTS

Based on the findings, the black pepper, *Piper nigrum,* has shown promising potential as a natural repellent and biopesticide (insecticide) against the sawtoothed grain beetle, *O. surinamensis*. This potential is being explained based on the repellence bioassay and the toxicity bioassay below.

Repellence Bioassay
It was found that both forms of treatments show repellency effects on *O. surinamensis*. This can be seen in the low number of insects found on the treated area of filter paper after 24 hours. In both treatments, high repellence activity (>75%) can be seen at lower concentrations (Table 2 & Figure 2). In the treatment using hot infusion, the most effective concentration is 25 g/L with a mean and standard error (SE) value of 5.70±1.055, while in the treatment using commercial oil, the repellence activity is the highest at 2.50 mL/L (5.40±0.400). It can be said

that the application of a hot infusion of 25 g/L of black paper powder worked similarly to using 2.50 mL/L of commercial oil to repel *O. surinamensis* in the treatment. On the other hand, the least effective treatment for hot infusion is at 100 g/L concentration (13.40±1.208) and at 1.25 mL/L (13.50±1.688) and 5.00 mL/L (13.40±0.510) concentrations for commercial oil. Only less than 50% of insects were repelled by these treatments. Statistical analysis shows that differences in the number of insects recorded in the treated area between concentrations were significant at P = 0.011 (χ = 11.219, df = 3) and at P = 0.039 (χ = 8.370, df = 3) for hot infusion and commercial oil, respectively. However, small differences in the number of insects detected between treatments were identified as not significant (U = 282.00, df = 1, P = 0.718).

Table 2. Repellence activity of hot infusion and commercial black paper oil against *O. surinamensis* after 24 hours

Treatment	**Concentration**	**Mean±SE**	
		Treated	**Untreated**
Hot infusion (g/L)	25	5.70±1.055	19.30±1.055
	50	11.00±2.098	14.00±2.098
	75	11.40±1.470	13.60±1.470
	100	13.40±1.208	9.40±0.894
	Total	9.44±0.922	15.12±0.922
Oil mL/L	1.25	13.50±1.688	11.50±1.688
	2.50	5.40±0.400	17.60±1.372
	3.75	8.88±2.125	14.63±2.360
	5.0	13.40±0.510	9.60±0.812
	Total	10.25±1.036	13.42±1.077

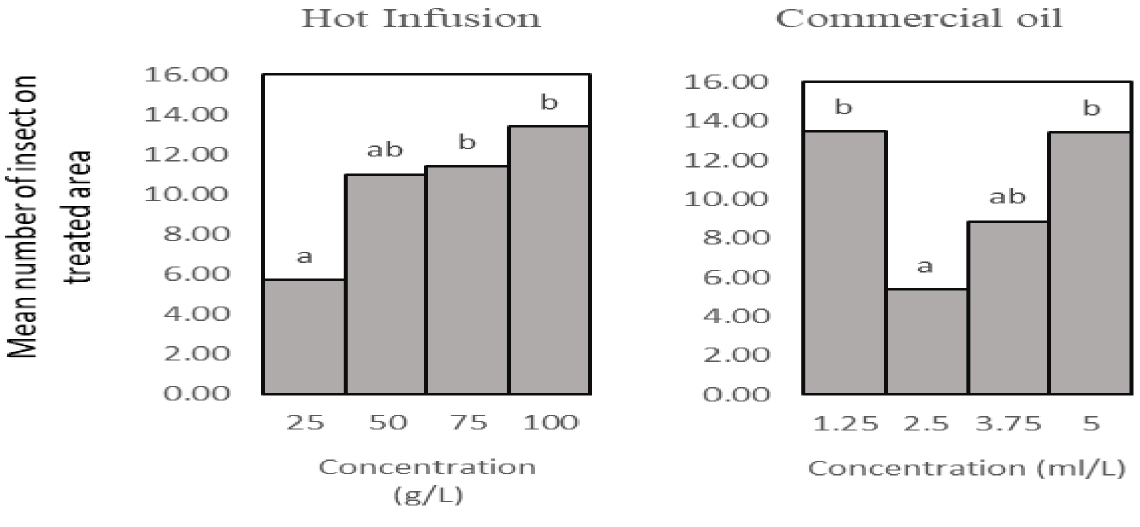

Figure 2. Significant differences in repellence effect of hot infusion of black pepper powder and commercial black paper oil on mean of *O. surinamensis* recorded in treated area using Mann-Whiteney U at *P<0.05*.

Toxicity Bioassay

The experiment shows that direct exposure to commercial black pepper oil caused mortality in *O. surinamensis,* and it was constantly increasing over the time of exposure. The highest number of dead insects after 48 hours of exposure was observed at concentration 3.75 mL/L with a mean and standard error value of 20.75±1.315 followed by concentration 2.50 mL/L (18.00±2.000). While only a low number (<20%) of dead insects were recorded at the lowest and highest concentrations. Relationships between concentration and time of exposure were examined using a two-way ANOVA. However, there was no significant interaction detected, so further analysis of differences was conducted using one-way ANOVA (for each parameter; concentration and time of exposure). Analysis of variance proved that these differences were significant at P = 0.000 (F = 20.089, df = 3).

Meanwhile, differences in insect mortality were also found to be significant between times of exposure (F = 5.880, df = 4, P = 0.000), particularly for concentrations of 2.50 mL/L and 3.75 mL/L. Figure 3 shows the multiple mean comparisons between the time of exposure for each concentration. Based on Probit Analysis, mortality was recorded to reach 50% after 6 hours and 24 hours of exposure at 3.75 mL/L and 2.50 mL/L (Probit: $LC_{50 6h}$ = 3.164 mL/L, $LC_{50 24h}$ = 2.448 mL/L), respectively. This showed that a concentration of 3.75 mL/L is the most effective in reducing the number of insect pests with the fastest time and mortality reaching 83% after 48 hours of exposure.

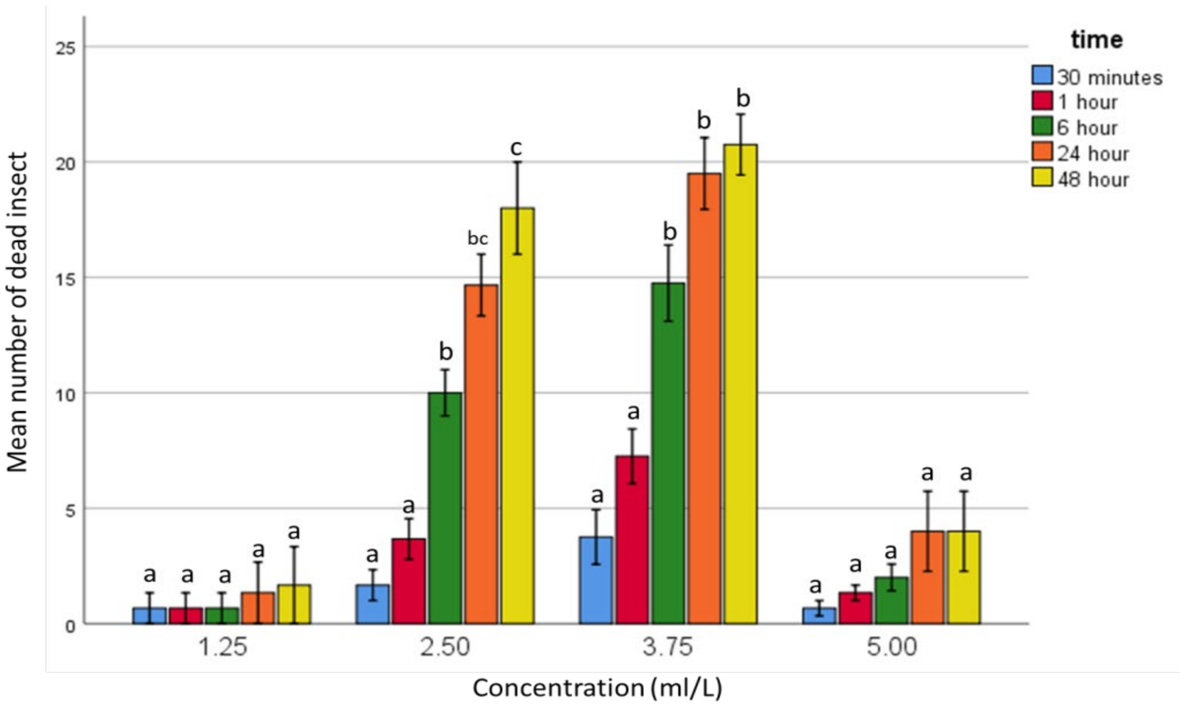

Figure 3. Number of *O. surinamensis* mortality after being exposed to eac concentration at different time of exposure. Small letter indicates multiple mean comparisons between time of exposures

DISCUSSION

A substance can be considered as a repellent when it causes the targeted pest to move away from the source of the odour (Nurul Huda et al. 2019; Kachhawaha et al. 2015; Ramirez et al. 2012). There are five types of repellent based on insect behaviour, which are expellency, irritancy, deterrence, odour masking and visual masking (Deletre et al. 2016). This study only demonstrated deterrence effect of black paper toward *O. surinamensis*. The method used in this study, however, does not indicate the effect of other four types of repellent.

Additionally, there is a strong likelihood that the percentage of repulsiveness will rise as exposure time increases. According to a study reported by Wagan et al. (2019), repellence activity of black pepper essential oil can last up to 96 hours on treated filter paper. The effectiveness of black pepper extracts was also reported by Ismail and Sleem (2021) against other storage pests, *Tribolium castaneum* and *S. oryzae,* after only 5 to 10 hours of exposure. They also reported that percentage repellence reached 100% for both exposure periods against *T. castaneum*, while repellence percentage was slightly lower for *S. oryzae* with 86.67% for the 5 hours period and 51.67% for the 10 hours period. Meanwhile, Ishii et al. (2010) reported that black pepper extract exhibits moderate repellence against *S. zeamais* at concentrations of 20 or 50 mg/mL.

Although statistically there is no significant difference between both treatments, in general, commercial oil treatment yields a better result in the mean number of repelled insects compared to a hot infusion of black pepper powder. For the commercial oil, the black pepper goes through distillation and other processes to produce highly concentrated oleoresin (oil+resin) (Spice Drop™ 2023). While simple hot infusion using black paper powder prepared in a laboratory may produce crude, less concentrated products with a high probability of different chemical compositions being extracted. Even so, based on the calculation, approximately equal amounts of peppercorn were used to produce dilutions of 25 g/L and 2.5 mL/L of hot infusion and commercial oil of black pepper respectively. In fact, based on the result, application of hot infusion at 25g/L of black paper powder worked similarly to using 2.5 mL/L commercial oil to repel *O. surinamensis* in the treatment. Unfortunately, there's not a lot of past literature about the chemical composition of black pepper hot infusion but a study from Gülçin (2005) shows that hot infusion of black pepper produces a high yield of phenolic compounds, approximately 54.3 µg. On the other hand, steam distillation produces a variety of chemical compounds, mainly terpenes and sesquiterpene hydrocarbons but limonene, δ-3-carene and ß-caryophyllene take the lead with respective concentrations of 15.24, 15.49 and 29.86% (Dinh et al. 2020). The variation in repellence activity could be the result of the difference in chemical composition extracted by the methods used.

In the toxicity bioassay, the toxicity of the black pepper oil at different dilution were expressed by LC_{50}. According to Paramasivam and Selvi (2017), LC_{50} is the concentration of biopesticide that can kill 50% of the pest population when exposed to the substance in controlled environment. There is a substantial difference in the mean number of *O. surinamensis* detected after treatment between concentrations and also between intervals of exposure in this toxicity investigation. The highest mortality observed after 48 hours of exposure is when the insects are treated with commercial black pepper oil at a concentration of 3.75 mL/L. However, the LC_{50} for this experiment was achieved when 2.5 mL/L concentration was used after 24 hours of exposure and 3.75 mL/L after 6 hours of exposure. The result proved that commercial black pepper oil shows high toxicity against *O. surinamensis* even at lower concentrations. Khani et al. (2012) reported that black pepper is most toxic to *Callosobruchus chinensis, Acanthoscelides obtectus, Corcyra cephalonica,* and *Ephestia cautella*, followed by *O. surinamensis*, *Sitophilus zeamais, Rhyzopertha dominica* and *Tribolium castaneum*. Similar results were also reported by Yonus et al. (2016) when they tested the feeding toxicity of crude alcoholic and hexane extracts of black pepper against *O. surinamensis*. They also discovered that hexane extract shows higher antifeedant properties by reducing the survival rate of *O.*

surinamensis to 67.4% compared to alcoholic extract which has a survival percentage of 88.5% at 10% concentration.

In this study, the increased insect mortality is obviously in parallel with the increased time of exposure, especially when it reached LC_{50} particularly for 2.5 mL/L and 3.75 mL/L. According to Prakash et al. (2013), the reason can be attributed to the accumulation of bioactive compounds in the commercial oil. However, insect mortality differences after LC_{50}, were found to be insignificant probably due to a small increase in mortality. Even after 24 hours of exposure, mortality recorded did not reach 100% for all concentrations. However, the possibility that total annihilation is reached if the time of exposure is extended cannot be excluded. Therefore, additional future research is required to support this claim.

The variation in results of the toxicity test can also be attributed to the difference in size, texture, or physiological and biochemical characteristics of the insect (Kiran & Prakash 2015). For example, in a study reported by Su and Horvat (1981), the effects of three isolated chemical compounds of black pepper were studied on *C. maculatus*, the cowpea weevil, where females had a higher body weight range than male cowpea weevils, resulting in a higher LC_{50}. However, in this study, gender bias was ignored following the literature (i.e., Nurul Huda & Noor Amni 2019; Nurul Huda & Noor Amni 2020; Kousar et al. 2021) which has noted that male and female *O. surinamensis* are similar in morphology and range of size except in a few fine structures of the forewing, pronotum, hind legs and external genitalia. In fact, according to Nurul Huda and Noor Amni (2020), food preference plays an important role in regulating *O. surinamensis* body size and all insects used were assumed to have similar morphology as they were mass reared under the same conditions thus excluding the influence of body size on the variation of the toxicity effect. Even so, fitness due to the different biochemical characteristics of the insect was not determined to justify this statement.

Another variation that can be observed in the result is low mortality in both the lowest and highest concentrations, which may be caused by the concentration of piperine in black pepper products. In a study reported by Samuel et al. (2016), a strain of malaria vector mosquitoes showed the highest larvicidal activity at 80% dose but the highest dose of piperine (100%) showed lower larvicidal activity. Another experiment on larvae of *Aedes aegypti* supported this study, where 100% mortality was achieved using a piperine concentration between 0.85 and 1.11 µg/mL but as the piperine concentration increased, the mortality of the larvae decreased. The same study annotated that synergistic interactions with piperine as the main compound and other main compounds might be attributed to mortality (Morais et al. 2023).

Although the experiment did not identify any chemical constituent responsible for its repellence and toxicity actions, the petri dish was totally sealed during the tests, therefore, other than direct contact with chemicals, it is possible that fumigant action may also be responsible for the insecticidal effects of black pepper. Piperine might be responsible for fumigant activity and has been reported to cause mortality against larvae of *Aedes aegypti,* working in synergy with pyrethrin, plus piperine also contributed to aroma and pungency (Samuel et al. 2016; Su & Horvat 1981). Another compound that might be responsible is the highly volatile monoterpenoids such as limonene. Monoterpenoids are highly toxic and are able to penetrate through the cuticle to enter the insect body and cause disruption in physiological functions (Khani et al. 2012). Limonene is indicated to have fumigant properties and capable of neurotoxic effects through inhibition of the acetylcholinesterase (AChE) enzyme or inhibition of reproduction and growth regulation (Aref et al. 2015; Khani et al. 2012). For contact toxicity, two amide compounds, pipercide and guineensine are known to have paralysing effects on *C. maculatus* when applied to the dorsal thorax (Su & Horvat 1981).

In this study, there is no possibility that beetle mortality was solely due to lack of oxygen in fully closed container (petri dish). Petri dish provides enough oxygen to starving *O. surinamensis* to last more than 4 days with no exposure to the biopesticide. In fact, not all beetles in the treatments died after 48 hours observation. However, there is possibility that physiological changes which lead to mortality happened on the insect due to exposure to biopesticide. Karise and Mänd (2015) describe that sublethal effect of pesticides can caused changes in the function of neural or muscular tissues lead to insufficiency in autonomic process such as thermoregulation, respiration and water balance. Meanwhile, according to Lord (1949), pesticides that affect insect respiration can be divided into two categories: those that stimulate respiration and those that suppress respiration.

Overall, the results of this study emphasised that black pepper has high potential to be used as an insect repellent and biopesticide for household use. Only simple preparation is needed to produce a hot infusion of black paper powder, while commercial oil used for cooking is readily available in the market. Dilution at lower concentrations is effective enough to repel this insect and the possibility of fumigant action enables application to suitable materials like filter paper without having to apply directly to the product (i.e., grains, cereal, etc.), which would affect product quality. There is great potential for future commercialization in the form of pesticide oil, but many elements of application must be studied, notably to control *O. surinamensis* since this beetle infected food product.

CONCLUSION

The effectiveness of black pepper, *Piper nigrum,* as a repellent and biopesticide (insecticide) against the sawtoothed grain beetle, *O. surinamensis,* is evaluated in this study. Hot infusion of black pepper powder and dilution of commercial black pepper oil for cooking, which are available in the market despite the simple and accessible preparation method, are effective in repelling *O. surinamensis* at low concentrations. Meanwhile, toxicity effects were found to vary at different concentrations and times of exposure. Too low a concentration seems not effective enough to cause adequate mortality to the pest within the period of exposure studied. However, there is no doubt that more exposure time increased insect mortality, as observed at concentrations of 3.75 mL/L and 2.50 mL/L. Findings from this study demonstrated the accessibility and effectiveness of *P. nigrum* as a novel bio-insecticide or a simple, affordable and sustainable household solution for the management of storage pests. Either way, the versatility of *P. nigrum* can reduce food spoilage and waste.

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AUTHORS DECLARATIONS

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Conflict of Interest
There is no competing financial interests or personal relationships among authors that could have appeared to influence the work reported in this paper.

Ethics Declarations
No ethical issue required for this research.

Data Availability Statement
This manuscript has no associated data.

Authors' Contributions
Nurul Farah 'Aina Anuar (NFAA) and Nurul Huda Abdul (NHA) conceived the research and designed the experiments. NFAA performed the experiment and collected the data with NHA supervision. NFAA and NHA participated in the interpretation of the data. NFAA and NHA wrote the paper and participated in the revisions of it. Both authors read and approved the final manuscript.

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