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Insecticidal and repellent activities of *Nezara viridula* secretions and hydro-distilled hexane extracts of *Petiveria alliacea* against *Sitophilus oryzae*

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Abstract

The rice weevil, *Sitophilus oryzae* is a major pest of stored cereals worldwide, causing significant post-harvest losses and reduced grain quality. Synthetic insecticides and fumigants are widely used for its control but their associated problems have necessitated the search for safer and sustainable alternatives. This study evaluated the insecticidal and repellent effects of insect-derived secretions from *Nezara viridula* and semi-volatile constituents from *Petiveria alliacea* on adult *S. oryzae* under laboratory conditions. Secretions from *N. viridula* were obtained using whole-body extraction and fractionated into hexane, ethyl acetate and methanol fractions, while constituents from *P. alliacea* leaves were extracted via hydro-distillation and analyzed using Gas Chromatography–Mass Spectrometry. Bioassays were conducted to assess mortality and repellency of *S. oryzae* at different exposure periods and concentrations using treated rice grains and Y-tube olfactometer assays. Experiments were arranged in completely randomized designs, and data were analyzed using analysis of variance, with means separated using Least Significant Difference at a 5% level of significance. Ethyl acetate fraction of *N. viridula* had the highest yield (53.4%), followed by methanol (7.77%) and hexane (1.94%). All fractions and crude methanolic extract of *N. viridula* caused significantly higher mortality of *S. oryzae* compared to the control, with the crude extract causing up to 62.5% mortality at 72 hours. Similarly, n-hexane constituent of *P. alliacea* contained twenty-two compounds, with 9-octadecenoic acid (50.63%), hexadecanoic acid (27.40%), and stigmasterol (5.41%) as major constituents. The constituents exhibited strong insecticidal activity, with mortality increasing in a concentration-dependent manner and reaching 80.0% at 30% (v/v) after 96 hours. Both *N. viridula* secretions and *P. alliacea* constituents elicited mortality and repellent activity on *S. oryzae.* These findings suggest that both insect-derived semiochemicals and plant derived oils possess promising bioactive properties for the management of *S. oryzae*. Their use could provide environmentally friendly alternatives to synthetic insecticides and may be further explored for integration into sustainable stored grain protection strategies

Keywords: *Nezara viridula* secretions, *Sitophilus oryzae* repellence, Semiochemicals, Gas Chromatography-Mass Spectrometry

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INTRODUCTION

Stored grain losses caused by insect pests remain a major constraint to global food security, particularly in staple crops such as rice (*Oryza sativa* L.) (Akhtar *et al.,* 2015; Da Silva Costa *et al.,* 2016; Babendreier *et al.,* 2020). Insects belonging to genera *Sitophilus, Tribolium*, and *Sitotroga*, cause severe harm to stored cereals grains (Kumar, 2017). Among the most destructive storage pests, which is considered the most important species is the rice weevil, *Sitophilus oryzae* L. (Coleoptera: Curculionidae) (Yan *et al.,* 2014; Akhtar *et al.,* 2015; Devi *et al.,* 2017). It significantly reduces grain quantity and quality during storage (Doherty *et al*., 2023). The activities of the pest culminate in loss of grain weight, nutrients and seed viability, thus making the grains vulnerable to contamination by mites and fungi (Da Silva Costa *et al*., 2016; Athanassiou *et al.,* 2017; Zakladnoy, 2018).

Control of this pest largely depends on synthetic insecticides, such as methyl bromide and phosphine, but the continued use of these chemicals poses serious concerns including the development of resistance, environmental contamination and harmful residues that affect human and animal health (Bhargude *et al*., 2021). For example, methyl bromide has been prohibited since 2005 due to its negative impact on air quality and the potential health risks of respiratory and neurological diseases in humans (Eastmond and Balakrishnan, 2010; Park *et al.*, 2020; Wang and Tang, 2014), and the effectiveness of phosphine fumigation is being compromised by the emergence of chemical resistance in pests (Daglish *et al*., 2014; Nguyen *et al*., 2016; Nayak *et al.,* 2020; Aulicky *et al*., 2022).

In response to these challenges, attention has shifted toward various alternatives for the management of *S. oryzae*. Some methods that have been tested by many researchers include irradiation/radiation (Follett *et al*., 2013; Nasr *et al*., 2022), heat treatment (Yan *et a*l., 2014; Wang and Tang, 2014), ozone treatment (Bonjour *et al.,* 2011; Xinyi *et al.,* 2017) and the use of cold plasma (Bourke *et al*., 2018; Ziuzina *et al*., 2021). Semiochemical-based materials have been used in modifying the behaviour of stored product insect pests, including *S. oryzae* (Phillips, 1997; Cao *et al.*, 2023). Compounds derived from natural sources have shown to possess high potency, low toxic effects on humans and are therefore increasingly preferred by consumers (Hossain *et al*., 2025). Insects themselves produce chemical secretions that function in defense and communication, many of which exhibit repellent or toxic effects on other insect species.

The southern green stink bug *Nezara viridula* (L.) is a highly polyphagous pentatomid pest of worldwide distribution, damaging soyabean, cowpea, rice, maize, cotton and tobacco (Knight and Gurr 2007; González *et al*., 2012). The bug is known to release defensive secretions containing aldehydes and other volatile compounds with bioactive properties (Aldrich, 1988; Borges *et al*., 1999). For example, early work by Malouf (1933) demonstrated that secretions of *Nezara viridula* are irritating to the lips, characterized by a strong aromatic odour, and alkaline in nature based on litmus tests. Despite some studies on the chemical composition and ecological function of *N. viridula* secretions, their potential application in stored-product pest management, particularly against primary pests such as *Sitophilus oryzae*, remains largely unexplored.

Additionally, plant-based active substances have been reported to have possess insecticidal properties (Akinbuluma *et al.,* 2021; Al-Harbi *et al.,* 2021; Widiyaningrum and Candrawati, 2021). For example, plant essential oils (EOs), that is, the highly volatile, aromatic yields obtained from plants (Naeem *et al.,* 2018) possess insecticidal, repellent and antifeedant properties, making them promising candidates for pest management (Isman, 2000; Regnault-Roger *et al.*, 2012). One of the promising EOs in insect pest management is that from the Guinea hen weed *Petiveria alliacea* L. It is a medicinal plant known for its diverse bioactive compounds, including sulfur-containing constituents and fatty acids, which have demonstrated antimicrobial and pesticidal potential (Kim *et al*., 2006) but whose efficacy against *Sitophilus oryzae* has remained limited.

We hypothesized that the secretions from *Nezara viridula* and volatile constituents from *P. alliacea* at different concentrations have insecticidal properties against *S. oryzae*. Specifically, we conducted experiments to determine (1) the mortality and repellent effects of secretions from *Nezara viridula* on *Sitophilus oryzae,* and to evaluate (2) the effect of *Petiveria alliacea* leaves on the insect pest. Exploring the efficacy of these natural products could provide valuable insights into the development of safer and more sustainable pest management strategies.

MATERIALS AND METHODS

Experimental locations

The study was conducted at the Entomology Research Laboratory, Department of Crop Protection and Environmental Biology (CPEB), University of Ibadan, Ibadan, Nigeria. Laboratory experiments were carried out under ambient conditions of 27 ± 2°C temperature and 65 ± 5% relative humidity. Olfactory bioassay was performed at the Insect Chemical Ecology Laboratory, CPEB, while extraction and chemical analyses were conducted at the Chemistry Laboratory, University of Ibadan, Ibadan, Nigeria.

Source and preparation of rice grains

Rice grains (FARO 44 variety) were obtained from Adom Agro-Allied Industry, Ibadan, Nigeria. Prior to use, the grains were disinfested by freezing at −18 °C for one week using a deep freezer (Hisense Chest Freezer, 95 L Fast Freezer, Silver, R600). To prevent mold growth and allow acclimatization to laboratory conditions, the grains were subsequently air-dried under ambient laboratory conditions before use.

Insect culture

A laboratory culture of *Sitophilus oryzae* was established using infested rice grains sourced from Bodija Market, Ibadan. Adult weevils were introduced into six 1 L Kilner jars containing clean rice grains (250–300 g per jar) and allowed to mate and oviposit for 7 days. Thereafter, parent adults were removed, and newly emerged (teneral) adults were used for all bioassays. Adult *Nezara viridula* were collected from the Teaching and Research Farm (TRF), University of Ibadan, using hand-picking and sweep-netting methods. The TRF is located in Oyo State, Nigeria (Latitude 07°27′15.5″ N, Longitude 03°53′31.1″ E; elevation: 194 m above sea level). Collected samples were preserved in methanol-filled dark vials and subsequently identified at the Insect Museum, CPEB.

Insecticidal materials

Fractionation of *N. viridula* secretions

Whole-body extraction was carried out by soaking 200 insects (10.96 g) in 25 mL of methanol for 14 days under dark conditions. The extraction was repeated, and the resulting filtrates were combined and concentrated using rotary evaporation to obtain the crude extract. The crude extract (3.09 g) was subsequently fractionated sequentially with *n*-hexane and ethyl acetate using a separatory funnel to obtain non-polar and moderately polar fractions, respectively, while the residual phase constituted the methanol fraction. The recovered fractions were concentrated under reduced pressure, and the dry weight of each fraction was recorded.

Leaves of *Petiveria alliacea* were collected from an open field at the Teaching and Research Farm, University of Ibadan, Ibadan, Nigeria. The leaves were air-dried for two weeks and subsequently pulverized using a mechanical crusher (flour-milling machine, Model AA-26; dimensions: 26 × 75 × 26 cm) at Ajibode Local Store, Ibadan, to increase the surface area for extraction. Essential oil was extracted from 100 g of the pulverized leaf material by hydrodistillation using a modified Clevenger-type apparatus. The oil was collected in *n*-hexane, stored in amber vials, and preserved for further analysis. The sample was analyzed using gas chromatography–mass spectrometry (GC–MS) (Agilent 6890A GC coupled with 5973C MS). Compounds were identified based on standard procedures.

Insecticidal Activity
Bioassay treatments

Crude extract and solvent fractions of *Nezara viridula* were prepared at 5% (w/v) by dissolving 0.5 g in 10 mL methanol. Similarly, hexane-derived constituents of *Petiveria alliacea* were prepared at concentrations of 10%, 20%, and 30% (v/v) in methanol. Methanol alone served as the control in this experiment.

Mortality bioassay

Adult mortality bioassays were conducted using treated rice grains. In separate experiments, twenty grams (20 g) of rice grains were treated with 0.5 mL of either fraction extracts or compounds derived from the *n*-hexane extract of *Petiveria alliacea* and subsequently air-dried. Ten adult *Sitophilus oryzae* (five complementary pairs) were introduced into each Petri dish and experimental container. Treatments were arranged in a Completely Randomized Design (CRD) with eight replicates.

Mortality was recorded at 24, 48, and 72 hours for fraction extract treatments, and at 24, 48, 72, and 96 hours for *P. alliacea* extract. Insects were considered dead when they showed no response to gentle probing. In all cases, observed mortality was corrected using Abbott’s formula (Abbott, 1925).

Corrected mortality (%) =

$$\text{Corrected Mortality (\%)} = \frac{M_t - M_c}{100 - M_c} \times 100$$

equation 1

Where MT represents the mortality in treatment and MC represent the mortality in control.

Repellency bioassay
Y-tube olfactometer assay

A Y-tube olfactometer was used to assess the behavioural response of adult *S. oryzae* to solvent extracts of *N. viridula* secretion. Filter paper treated with the test extract was placed in one arm of the olfactometer, while filter paper treated with methanol served as the control in the opposite arm. Airflow was maintained at 60 mL/min to ensure even distribution of volatiles. Twenty adult weevils were introduced individually at the base of the Y-tube (internal diameter 0.5

cm, stem length 4 cm, arm length 5.5 cm) and allowed to make a choice within 5 minutes. The number of insects entering each arm was recorded. Percentage repellency (PR) was calculated using the formula:

$$PR = \frac{N_c - N_t}{N_c + N_t} \times 100 \qquad \text{equation 2...}$$

(Akinbuluma *et al.,* 2017)

Where *Nt* represents the number of insects in the treated arm and *Nc* represents the number of insects in the control arm. Negative values of repellency were recorded as zero. Data were used to determine percentage repellency of each treatment.

Half-filter paper disc assay

To evaluate repellent effect of compounds derived from the *n*-hexane extract of *P. alliacea* leaves, a half-filter paper disc method was used. Filter paper discs were divided into two equal halves, one half treated with individual concentration of *P. alliacea* extract and the other with methanol as control. The treated and control halves were placed together in a Petri dish to form a full disc. Ten adults of *S. oryzae* were released at the center of each Petri dish. The distribution of the adult insects on treated and control halves was recorded at 30 and 60 minutes after introduction. Percentage repellency was calculated using the same formula described in equation 2. Negative values were standardized to zero prior to analysis.

Data analysis

Data on mortality and repellency were analyzed using analysis of variance (ANOVA), and treatment means were separated using Least Significant Difference (LSD) at 5% level of significance.

RESULTS

Weights of solvent fractions obtained from the secretions of *Nezara viridula*

Figure 1 showed the weight of the solvent fractions from the secretions of *Nezara viridula*. The ethyl acetate fractions had the highest weight (1.65 g) followed by the methanol fraction (0.24 g) while the hexane fraction had the lowest weight (0.06 g). The hexane, ethyl acetate and methanol fractions respectively weighed 1.94%, 53.4 % and 7.77% of the total weight obtained from the crude extract.

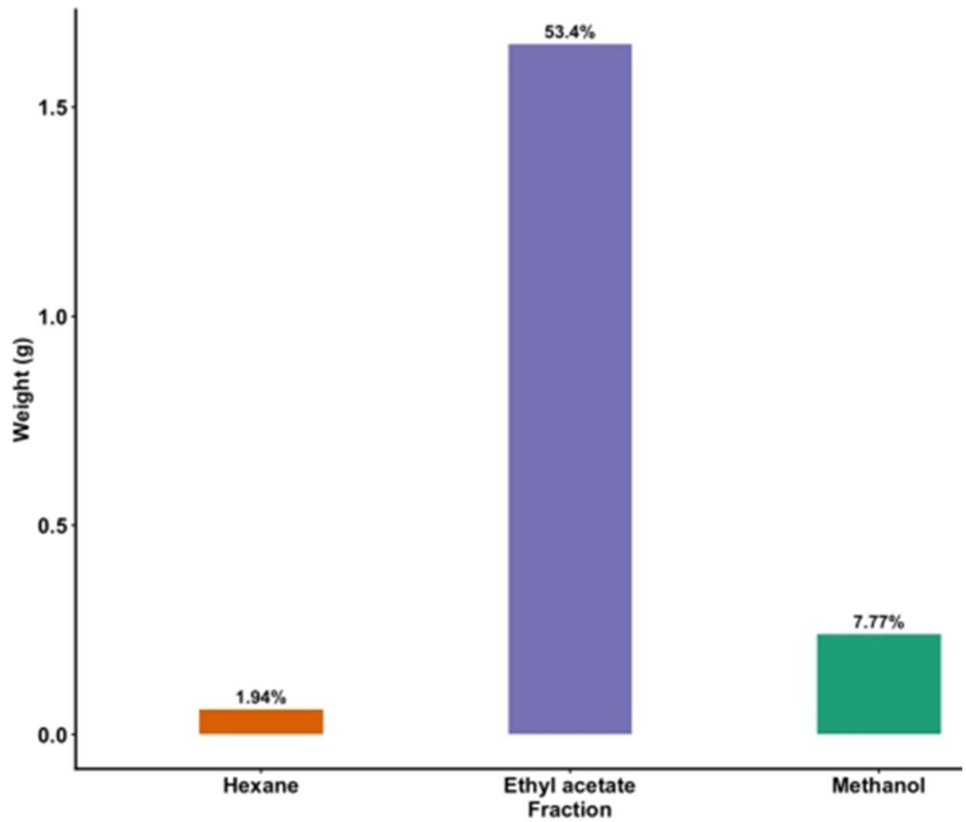

Figure 1: Weight of fractions of secretions of *Nezara viridula*

Percentage Composition of GC-MS detectable constituents of hexane extract from *P. alliacea* leaves

The GC-MS analysis identified 22 constituents in the n-hexane extracted from leaves of *P. alliacea* is presented on Table 1. The most abundant compounds were 9-octadecenoic acid (50.63%) and n - hexadecanoic acid (27. 40 %), while the minor compounds include Dodec - 2 - en - 1 - yl propyl carbonate (0.10%), 1, 3 cyclo pentadiene (0.11%) Octadecane, 1 – chlorine (0.13%) and undecane (0.28%).

Table 1: GC–MS constituents of *n*-hexane extract of *P. alliacea* leaves

Compounds	**Retention time (mins)**	**% Composition**
Undecane	4.442	0.28
1 , 3 – cyclopentadiene	4.687	0.11
Dodec -2 - en – yl propyl carbonate	12. 230	0.10
Tetra decanoic acid	12.841	0.30
Octadecane – chloro-	13.130	0.13
Pentadecanoic acid	13.863	0.38
Methyl hexadec -9 –enoate	14.685	0.45
n – hexadecanioc acid	15.030	27.40
Ergosta – 4, 6 , 22 – trien – 3 beta – ol	16.263	0.40
9 – Octadecenoic acid	16.663	50.63
Octadecanoic acid	16.785	7.01
Hexadecadiene	18.096	0.41
Hexadecadiene acetate	18.218	0.39
Naphthalenone	18.340	0.63
2 (H) –Naphthalenone	18.429	0.82
Docosanediol	19.662	0.35
Ergost – en – 3 – ol	19.692	2.80
Dihydrotachysterol	20.440	0.70
Stigmasterol	20.929	5.41
Stigmasta – 3, 5 – diene	21.196	0.73

Mortality Effect

Effects of secretions from *N. viridula* on the mortality of adult *S. oryzae*

The percentage mortality of adult *Sitophilus oryzae* treated with the solvent fractions of secretions of *Nezara viridula* relative to the methanol treated control is presented in Figure 2. Both the treatment and time were significant. In 24 h, percentage mortality of *S. oryzae* was significantly higher ($p < 0.05$) in the crude methanol extract than in the methanol-treated control. In both 48 h and 72 h after infestation, mortality caused by the crude extract (37.5%), ethyl acetate fraction (20.85%) and hexane fraction (29.18%), were significantly higher than those of the methanol-control. The crude extract caused the highest mortality on *S. oryzae*, although not significantly different from the mortality caused by hexane fraction in all the days of the trials (Figure 2). The cumulative pattern of activity of the treatments on *S. oryzae* was crude fraction (62.5 %) > hexane fraction (50.0%) > ethyl acetate (37.48%) and methanol fraction (37.48%).

Effects of hexane extract of *Petiveria alliacea* on the mortality of adult *S. oryzae*

The mortality effect of the hexane extract of *Petiveria alliacea* leaves on adult *S. oryzae* is presented in Figure 3. Mortality of adult *S. oryzae* was significantly higher ($p < 0.05$) in all treatment concentrations across the exposure periods compared to the methanol control. A clear concentration-dependent effect was observed, with the highest mortality consistently recorded at the highest concentration (30% v/v) throughout the duration of the experiment. At 96 h post-exposure, the 30% (v/v) treatment resulted in 80% mortality (Figure 3).

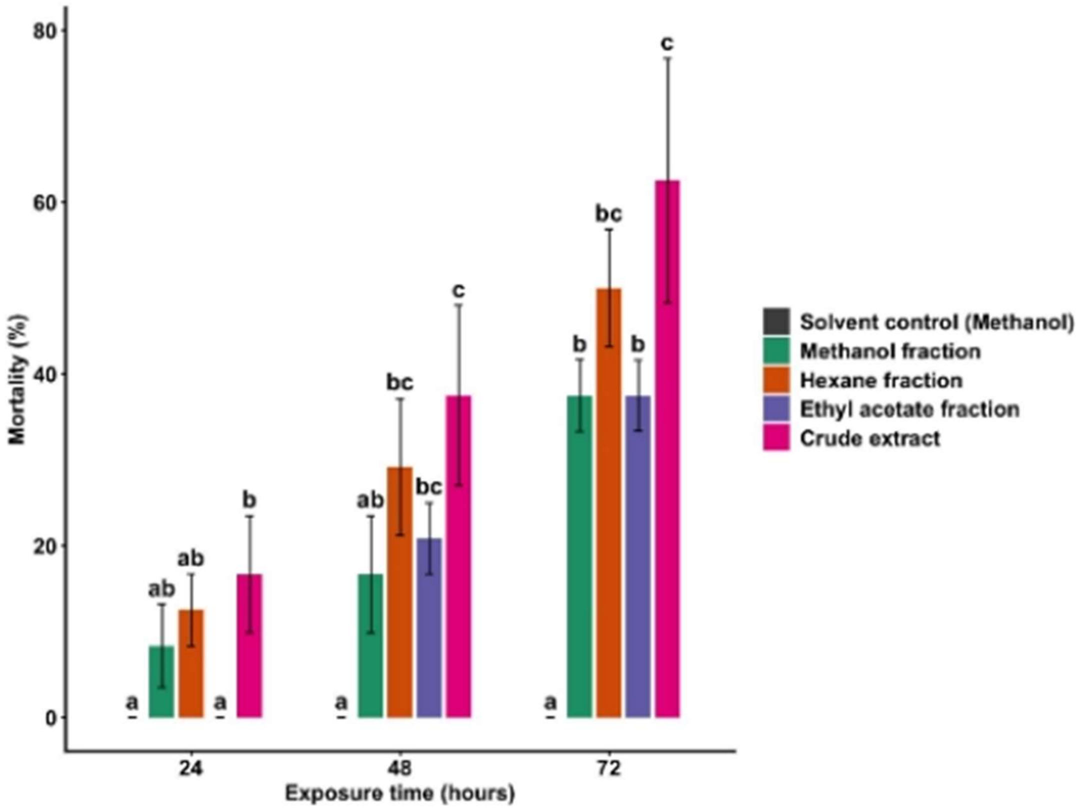

Figure 2. Effect of secretions of *Nezara viridula* on the mortality of adult *Sitophilus oryzae*

Bars within each group represent percentage mortality caused by the treatments within the hours of exposure. The solvent control (methanol) and the crude extract represent the negative and positive control, respectively. Different letters within each treatment group indicate statistically significant differences in mean percentage mortality of S. oryzae, while error bars represent ± SEM ($p < 0.05$, LSD; $n = 8$).

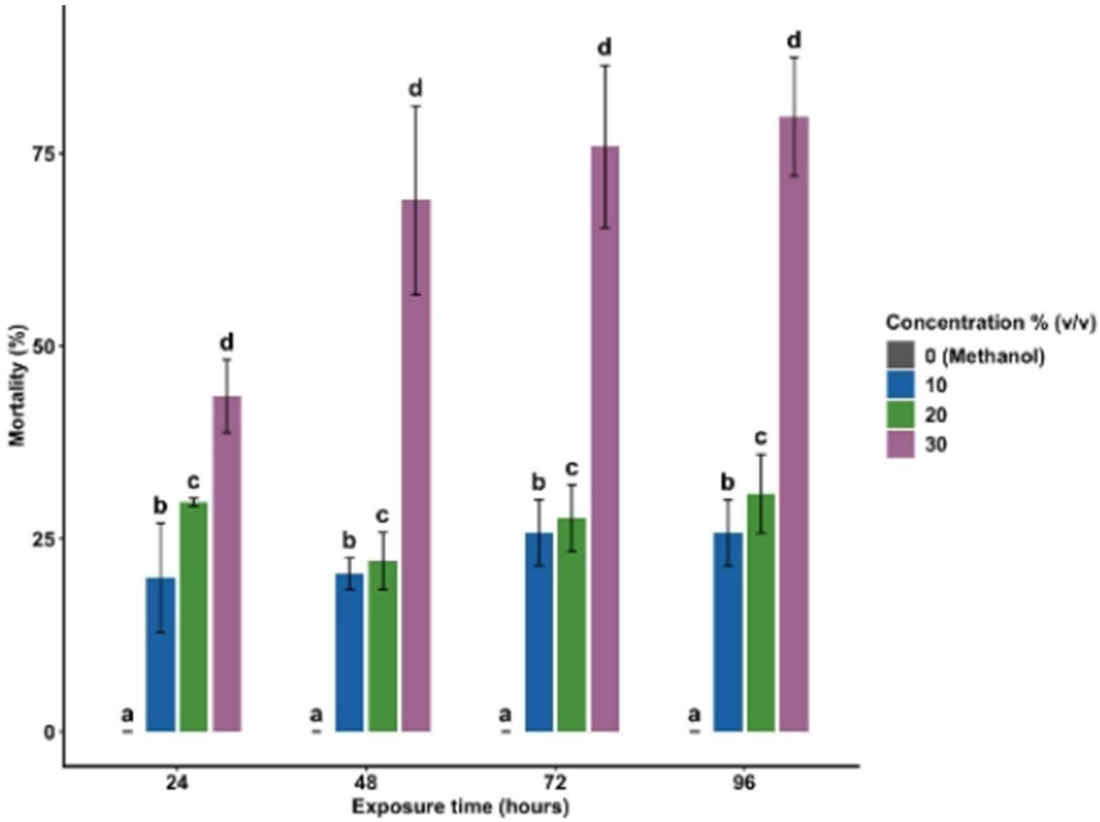

Figure 3: Effect of extract concentrations of *Petiveria alliacea* leaf on the mortality of adult *Sitophilus oryzae***.**

Bars within each treatment group represent percentage mortality caused by the treatment within hours of exposure. Different letters within each treatment group indicate statistically significant differences in mean percentage mortality of *S. oryzae*, while error bars represent ± SEM ($p < 0.05$, LSD; $n = 8$).

Repellent Effects

Repellent effect of secretions from *N. viridula* on adult *S. oryzae*

Repellent effect of secretions from adult *Nezara viridula* on adult *Sitophilus oryzae* is presented in Figure 4. The number of adult *S. oryzae* repelled by the methanol fraction (34%) was significantly lower ($p < 0.05$) than those repelled by the crude extract (80%), hexane fraction (95%) and ethyl acetate fraction (87%) of *N. viridula* secretions. However, we found no difference ($p > 0.05$) among the number of insects repelled by the crude extract, the hexane fraction and the ethyl acetate fraction. Unlike in the methanol fraction, the crude extract, as well as the hexane and ethyl acetate fractions caused above 50% repellence to *S. oryzae* (Figure 4).

Repellent effect of *Petiveria alliacea* on adult *Sitophilus oryzae*

We checked the repellent effect of hexane constitutents of *P. alliacea* at different concentrations on adult *Sitophilus oryzae.* We found a significant difference ($p < 0.05$)

between the number of insects repelled by concentrations of *P. alliacea* and the control at 30 mins and 60 mins of the set up (Figure 5). However, unlike in the 30 mins after set up, at 60 mins, *P. alliacea* at 30% and 20% (v/v) caused significantly higher repellent effect on *S. oryzae* than at the 10% concentration. In both period of the trials, the highest concentration of the essential oil (30% v/v) elicited the highest repellent effect (that is, 60.00 and 65.00 %, respectively).

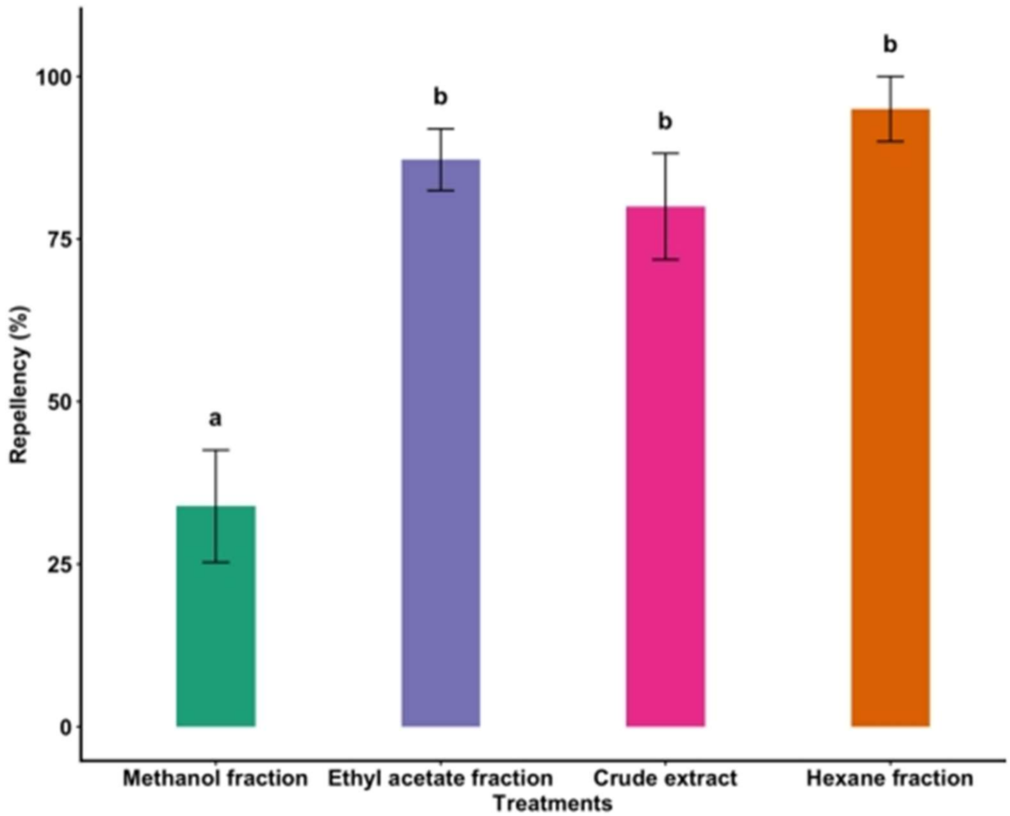

Figure 4. Repellent effect of secretions of *Nezara viridula* on adult *Sitophilus oryzae.*

Each bar represents the percentage of adult *Sitophilus oryzae* repelled by either the extract fraction or the crude extract. The percentage repellency of each fraction and the crude is relative to the methanol control, using the percentage repellency formula. Different letters within each treatment group indicate significant differences in mean percentage repellency, while error bars represent ± SEM ($p < 0.05$, LSD; $n = 20$).

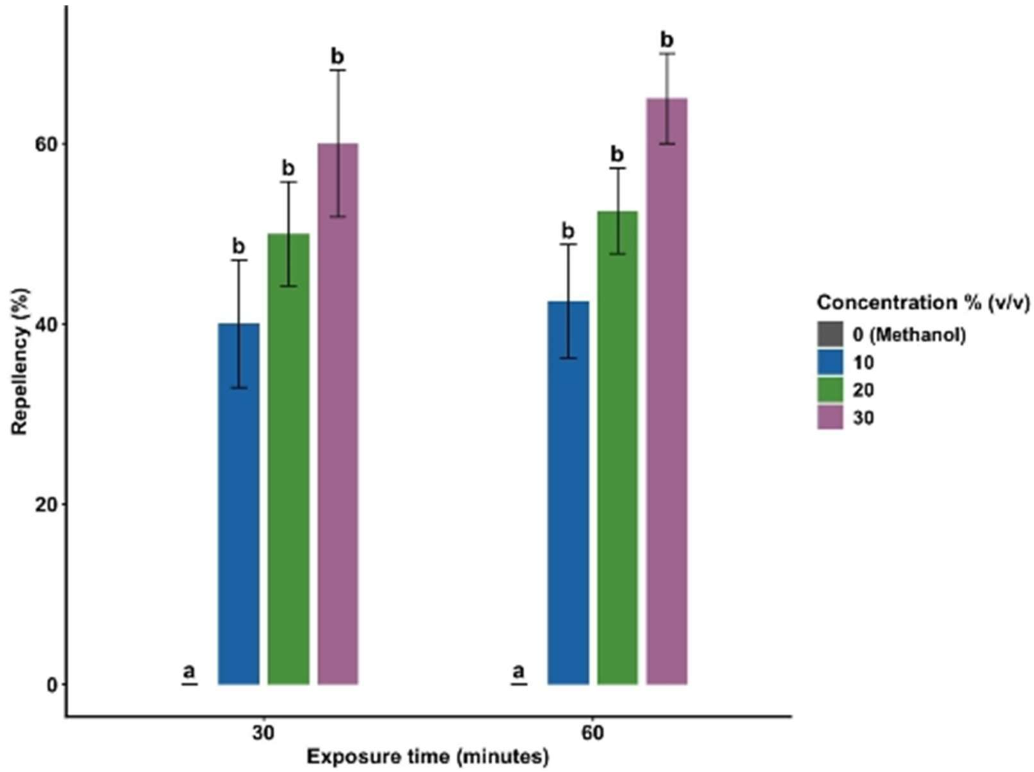

Figure 5. Repellent effect of *Petiveria alliacea* leaf extract on adult *Sitophilus oryzae*. Bars within each treatment group represent the percentage of adult *S. oryzae* repelled at different extract concentrations over the exposure period. Different letters within each treatment group indicate significant differences in mean percentage repellency, while error bars represent ± SEM ($p < 0.05$, LSD; n = 20).

DISCUSSION

In the management of insect pests, widespread use of synthetic chemicals has raised serious concerns worldwide, including ozone depletion, pesticide residues, human health problems, and environmental pollution (Kostyukovsky *et al*., 2002a, b; Ogendo *et al*., 2008; Ayvaz *et al*., 2010; Lee *et al*., 2018a). Therefore, the development of bioinsecticides have become an important goal for researchers over the last few decades (Sousa *et al.,* 2015; Karabörklü and Ayvaz, 2023). Consequently, insecticides from natural products have been an important component that integrates other control methods and have been used in many agricultural control methods, including the control of stored-product pests (Ayvaz *et al*., 2010). Unlike the synthetic chemicals, these biopesticides have high biodegradability, lack of bioaccumulation, and low toxicity to mammals (Regnault-Roger 1997; Isman, 2000; Ayvaz *et al*., 2009; Karabörklü, 2014).

The present study aimed to evaluate the bioactive potential of insect-derived secretions from *Nezara viridula* and plant-derived constituents from *Petiveria alliacea* against *Sitophilus oryzae*. Specifically, the study assessed their insecticidal and repellency activities, with a view to determining their suitability as environmentally friendly alternatives to synthetic insecticides for the protection of stored grains.

In this study, distinction between the crude methanol extract and its solvent fractions has implications on how compounds of different polarity could contribute differently to the bioactivity of *Nezara viridula* secretions. While the crude extract represents the total chemical profile of the insect, encompassing compounds across a wide polarity range, resulting solvent partitioning reveals a functional segregation of metabolites that is ecologically meaningful.

A key adaptive feature of the pentatomid bugs is the presence of well-developed scent glands (Rohanová *et al*., 2016; Weiler *et al.,* 2017) which secrete a variety of defensive compounds that deter predators. They synthesize a broad spectrum of semiochemical compounds that regulate communication and ecological interactions, including pheromones, allomones, synomones, and kairomones. Among these, protective allomones secreted by the metathoracic glands are well studied and play a central role in chemical defense (Shakirzyanova *et al*., 2025). Therefore, such bioactive compounds from *Nezara viridula* are expected to partition preferentially into solvents of varying polarity.

Variation in extraction yield among fractions of *N. viridula* secretions was observed, with the ethyl acetate fraction producing the highest yield and the hexane fraction the least. In an earlier study by Akbar *et al.* (2021), among the solvent fractions, hexane, ethyl acetate and methanol that were used in extracting the seaweed, *Padina sp.*, hexane gave the least yield, which is similar to what was found in this study. This variation is likely attributable to differences in solvent polarity and the nature of compounds extracted. The relatively low yield of the hexane fraction suggests that fewer non-polar compounds were present in the crude extract compared to moderately polar constituents.

Crude extract and all solvent fractions of *N. viridula* secretions significantly caused mortality of adult *S. oryzae*, with mortality increasing over time. The observed insecticidal activity of the fractions may be attributed to the volatility and concentration of active compounds within the fractions. Apart from the crude extract, the hexane fraction notably demonstrated higher efficacy than the ethyl acetate and methanol fractions, suggesting that non-polar compounds may play a major role in toxicity. Although the hexane fraction yielded a smaller quantity of extract, its efficacy indicates that biological activity is driven by the presence of potent compounds rather than extract yield. Indeed, compounds known for their defensive roles (Waterhouse *et al*., 1961), including *trans*-2-hexenal and *trans*-2-decenal, have been reported in non-polar and moderately polar extracts of *Nezara viridula* and related pentatomids (Aldrich, 1988; Pavis *et al*., 1994). Non-polar extracts often exhibit stronger insecticidal activity against stored-product pests, particularly *Sitophilus* species (Souza *et al.,* 2010; Akinbuluma *et al*., 2017). Similarly, hexane extract of *Tephrosia vogelii* Hook. f. had a relatively higher efficacy in causing mortality to *S. zeamais* than its acetone and ethanol counterparts (Koona *et al.,* 2007). It is interesting that the efficacy of hexane extract has also been reported against other insects. High toxicity of hexane extracts from *Hyptis carinatum* against larvae of *Aedes aegypti* was reported by Da Silva *et al*. (2013). This further supports the effectiveness of non-polar extracts against insect pests.

Similarly, repellent activity of *N. viridula* secretions varied among fractions, with the crude extract, hexane and ethyl acetate fractions exhibiting repellency values exceeding 50%. This suggests that certain volatile compounds within these fractions are responsible for behavioural deterrence in *S. oryzae*. A recent study by Ochola *et al.* (2026) demonstrated that insect-based oils, used either alone or as bioactive adjuvants, improved the stability, persistence, and efficacy of plant-derived mosquito repellents.

In addition, *Petiveria alliacea* exhibited considerable variation in the chemical composition of its hydrodistilled *n*-hexane extract, with GC–MS analysis indicating a profile dominated by lipophilic and semi-volatile constituents. Variability in plant-derived chemical composition is well documented and has been shown to significantly influence biological activity. Plant secondary metabolites vary in response to genetic, environmental, and physiological factors, thereby affecting their bioactivity (Yang *et al.,* 2018; Elshafie *et al.*, 2023). Major constituents identified in this study, such as *n*-hexadecanoic acid, 9-octadecenoic acid, and stigmasterol, are long-chain, non-volatile lipophilic compounds, in contrast to the terpene-rich essential oils commonly reported in other studies. The extracts in this study was therefore characterized predominantly by fatty acids, hydrocarbons, and phytosterol derivatives, which are typically associated with plant cuticular waxes and membrane lipids (Kunst and Samuels, 2009; Yeats and Rose, 2013), rather than typical volatile oil fractions. This chemical profile indicates a predominance of semi-volatile and high molecular weight compounds in the extract.

Remarkably, our extract exhibited strong insecticidal activity against *S. oryzae*, with mortality increasing in a concentration- and time-dependent manner. This bioactivity may be attributed to the combined effects of its constituent compounds, particularly fatty acids and other lipophilic molecules, which are known to disrupt insect physiological processes, including membrane integrity and respiration (Isman, 2000; Shahzad and Manzoor, 2021; Kaczmarek *et al.,* 2024). Plant-derived extracts and their bioactive constituents have been widely reported to be effective against stored-product pests, including *Sitophilus* species (Bekele and Hassanali, 2001; Bouda *et al*., 2001; Aboaba *et al*., 2019; Akinbuluma, 2020; Akinbuluma *et al.* 2021; Akinbuluma *et al.,* 2025). Similarly in a recent study by Akintola *et al.* (2026), fractioned extracts of *Petiveria alliacea* caused 100% mortality of the larger grain borer, *Prostephanus truncatus* (L.) under 24 h. This level of mortality was not significantly different from the mortality caused by the cypermethrin, a synthetic, broad-spectrum pyrethroid insecticide.

In addition to their toxic effects, all tested concentrations of the *P. alliacea* extract exhibited strong repellent activity against *S. oryzae*. This repellency may be linked to the presence of some semi-volatile compounds that produce odours capable of interfering with insect host-location, orientation and feeding behaviour. Although not a classical essential oil, the semi-volatile fraction of the hexane extract of *Petiveria alliacea* likely contributes to the behavioural disruption of *Sitophilus oryzae*, in a manner similar to plant-derived volatile compounds known to influence insect behaviour and host selection (Cao *et al*., 2023; Zhou and Jander, 2022). Navarro *et al.* (2005) demonstrated that several turmeric oil fractions have both repellency and antifeedant effects on test storage insects.

Overall, while the hydro-distilled hexane extract of *P. alliacea* demonstrated pronounced insecticidal effects, both treatments exhibited considerable repellency against *S. oryzae*. These findings suggest that plant-derived lipophilic and volatile constituents can act through multiple mechanisms, including toxicity and behavioural interference. Such compounds, in combination with insect-derived semiochemicals, may provide complementary strategies for pest management. Their integration could enhance efficacy and contribute to the development of sustainable and eco-friendly alternatives to conventional synthetic insecticides

CONCLUSION AND RECOMMENDATIONS

This study demonstrated that both insect-derived secretions from *Nezara viridula* at 5% (w/v) and plant-derived extracts from *Petiveria alliacea* at 10 - 30% (v/v) possess significant insecticidal and repellent activities against *Sitophilus oryzae*. The solvent fractions of *N. viridula*, particularly the hexane and ethyl acetate fractions, showed some bioactivity, while the hexane constituents of *P. alliacea* exhibited strong, concentration-dependent toxicity and repellency. These findings highlight the potential of both bioactive sources as effective alternatives to synthetic insecticides for the management of *S. oryzae* in stored rice.

The use of these natural products offers promising prospects for reducing the adverse effects associated with synthetic chemicals, including environmental contamination, pest resistance, and harmful residues in food products. Furthermore, the complementary actions of insect-derived semiochemicals and plant-derived bioactive substances suggest that their integration could enhance pest control efficiency in stored grain systems.

Future research should focus on the identification and characterization of specific bioactive compounds responsible for the observed effects, as well as elucidating their modes of action. In addition, investigations into formulation development, optimal application methods, and strategies to improve persistence and stability under storage conditions are necessary. Evaluating the combined effects of *Nezara viridula* secretions and *Petiveria alliacea* constituents could also provide valuable insights for developing more effective, eco-friendly pest management strategies.

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