

Assessment of *Aframomum melegueta*, *Pterocelastrus tricuspidatus* and *Bryophyllum pinnatum* as Potential Insecticidal Agents against *Sitophilus zeamais* in Stored Maize

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ARTICLE HISTORY

Received Date: 2ND May, 2025
Accepted Date: 8th August, 2025



http: www.njphr.nspri.gov.ng
ISSN: 2630-7022

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CONFLICT OF INTEREST: None

ETHICAL APPROVAL: Not Applicable



This is a publication of the
Nigerian Stored Products
Research Institute (NSPRI)

OPEN ACCESS

Abstract

Maize is highly vulnerable to infestation by the maize weevil (*Sitophilus zeamais*). The widespread use of synthetic insecticides in pest management has raised significant environmental and health concerns, necessitating the exploration of sustainable, plant-based alternatives. This study evaluated the insecticidal, repellent, and emergence inhibition of methanolic extracts from *Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum* against *Sitophilus zeamais* in stored maize. Standard phytochemical and antioxidant analytical techniques were used to assess the insecticidal efficacy of the plant extracts. Phytochemical screening revealed that *A. melegueta* possessed the highest phenols (10.65 mg/100g) and tannins (3.83 mg/100g) contents, while *P. tricuspidatus* recorded the highest flavonoids (3.90 mg/100g), saponins (1.44 mg/100g), and cardiac glycosides (8.31 mg/100g) levels. *B. pinnatum* showed the highest alkaloid content (7.85 mg/100g). Antioxidant activity assessed by DPPH radical scavenging showed strong activity across all extracts, with *A. melegueta* exhibiting the highest activity (74.13%). Bioassay results demonstrated a concentration and time-dependent mortality in *S. zeamais*, with *B. pinnatum* showing the highest mortality of 83.33% at 5% after 36 h, while *P. tricuspidatus* achieved 76.67% at 2%. Repellency assays showed that all extracts significantly deterred insect presence, with *P. tricuspidatus* exhibiting superior repellency even at lower concentrations. Additionally, adult emergence inhibition was most pronounced at 10%, with *P. tricuspidatus* and *B. pinnatum* recording 0.00% emergence within 12 and 24 hs, respectively. These findings highlight the potential of these plant extracts as eco-friendly insecticides. Their rich phytochemical composition, potent antioxidant properties, and strong bioactivity support their application in postharvest grain protection and integrated pest management (IPM) strategies.

Keywords:

Biopesticides, Candlewood, Insecticidal efficacy, *Sitophilus zeamais*, Wonder plant

Introduction

Storage insect pests pose a significant threat to food security, causing substantial damage to agricultural crops and resulting in considerable economic losses (Bajsa et al., 2023). *Sitophilus zeamais* is an economically significant pest in stored grains, causing up to 40% postharvest losses (Berhe et al., 2023) and compromising grain quality and safety. In regions where food insecurity is prevalent, these losses contribute to hunger and economic instability (Stathers & Mvumi, 2020). Although synthetic insecticides remain effective in controlling storage pests, their widespread use has raised serious concerns due to adverse effects on human health, animals, and the environment. Residues of these chemicals in stored produce have been linked to food safety issues, economic losses, and ecological damage, including soil and water contamination, as well as the rapid development of pest resistance (Raj et al., 2023). Many of these pesticides, such as organophosphates, organochlorines, and aluminium phosphide, are potential carcinogens and contribute to an estimated 300,000 deaths annually due to poisoning worldwide (Omoyajowo et al., 2018). These concerns have intensified the global search for safer, eco-friendly alternatives, particularly naturally derived compounds for managing insect pests in stored agricultural products (Fenibo et al., 2022).

How to cite:

Nwokpoku, D. E., Okike, O. O., Elemasho, M. K., Kijan, M. A., Eneke, I. E., Nwachukwu, F. E., Akah, C. I., Christopher, K., Ikeorah, N. N., Onyegbule, F. O., Awagu, F. E., & Inana, M. E. (2025). Assessment of *Aframomum melegueta*, *Pterocelastrus tricuspidatus* and *Bryophyllum pinnatum* as Potential Insecticidal Agents against *Sitophilus zeamais* in Stored Maize. *Nigerian Journal of Post-Harvest Research*, 3(5), 1-11.

Botanical insecticides, derived from plant extracts containing bioactive secondary metabolites, have gained increasing attention as sustainable pest control agents (Isman, 2020). Many plants produce allelochemicals such as alkaloids, flavonoids, tannins, and terpenoids with potent insecticidal, repellent, or growth-regulatory effects (Chaudhari et al., 2021). Despite growing interest in plant-based bioinsecticides, comparative studies evaluating their specific efficacy against key storage pests, such as *S. zeamais*, remain limited.

Aframomum melegueta, commonly known as alligator pepper or grains of paradise, is a tropical plant with culinary and medicinal uses. It has been reported to exhibit antitumor, anti-inflammatory, and antioxidant activities. The plant features narrow leaves and distinctive pink or lilac flowers, containing bioactive compounds such as alkaloids, flavonoids, and phenols (Ogban et al., 2021). *Pterocelastrus tricuspidatus*, known as candlewood, is a tree that grows up to 10 m tall and produces sweetly scented flowers followed by large numbers of very distinctive and attractive, bright-orange, lantern-shaped berries. The young leaves are red, but they mature to a glossy green colour. It has long been used in traditional medicine for its antimicrobial and insecticidal properties. Studies have shown that compounds such as triterpenoids and flavonoids in *P. tricuspidatus* contribute to its insecticidal activity against pests, including stored grain weevils (Razzaq et al., 2023). *Bryophyllum pinnatum*, also called the “mother of thousands” or “miracle plant,” is widely recognised for its diverse pharmacological properties. It has been traditionally used to treat fever, smallpox, otitis, cough, asthma, headache, convulsions, and general debility. Research has demonstrated that it exhibits antimicrobial, anti-ulcer, antihypertensive, antileishmanial, anticancer, antidiabetic, and immunomodulatory effects. Beyond its medicinal relevance, the plant has a rich phytochemical profile, suggesting potential for pest control applications. In addition to its therapeutic potential, extracts of *B. pinnatum* have demonstrated insecticidal activity, attributed to alkaloids and flavonoids, against various pests, including stored grain beetles and weevils (Shahreesh et al., 2023).

Despite these findings, there is limited information comparing the relative insecticidal efficacy of these plants against *Sitophilus zeamais*, a major pest responsible for substantial postharvest losses in stored maize. Therefore, this study evaluated the insecticidal effectiveness of *Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum*

pinnatum against *S. zeamais* under controlled laboratory conditions.

Materials and Methods

Biological materials

Plant materials used in the study were alligator pepper (*Aframomum melegueta*), candlewood (*Pterocelastrus tricuspidatus*), wonder plant (*Bryophyllum pinnatum*), maize grains, and maize weevil (*Sitophilus zeamais*).

Chemicals and reagents

Methanol and ethanol were obtained from Sigma-Aldrich (St. Louis, MO, USA), while DPPH and ascorbic acid were purchased from Merck (Darmstadt, Germany).

Collection of plant materials

The plant materials (*Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum*) were collected from Ebonyi State, Nigeria. The plants were identified taxonomically and authenticated at the Plant Sciences Department of the University of Port Harcourt, Rivers State. Voucher specimens were deposited in the departmental herbarium with the following reference numbers: *Aframomum melegueta* (UPH/V/001/2024), *Pterocelastrus tricuspidatus* (UPH/V/002/2024), and *Bryophyllum pinnatum* (UPH/V/003/2024). Maize grains were obtained from the National Seed Council of Nigeria, Southeast Zonal office.

Preparation of plant material

The fresh plant materials (*Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum*) were washed with tap water and then rinsed with distilled water. They were subsequently chopped and air-dried at room temperature. Each powdered sample (800 g) was extracted with 7.5 L of methanol in a clean air-tight container for 72 h at room temperature with occasional manual shaking to enhance solvent-solute interaction. The methanol extracts were filtered first through glass wool and then through Whatman No. 1 filter paper. The filtrates were concentrated to dryness under reduced pressure using a rotary evaporator at 50 °C. The dried extracts were stored in sterile, tightly sealed containers under refrigeration (4 °C) until use. The extraction yields obtained were 10.65%, 12.02%, and 9.17% for *Aframomum melegueta*, *Bryophyllum pinnatum* and *Pterocelastrus tricuspidatus*, respectively.

Phytochemical composition

The phytochemical constituents of each plant extract were determined following the official methods

described by Trease & Evans (2009) and Harborne (1998). Alkaloids were estimated through acid–base extraction and gravimetric measurement of the precipitate. Flavonoids were quantified using the aluminium chloride colourimetric assay, while saponins were determined by foam persistence and spectrophotometric analysis. Tannins were assessed through Folin–Denis titration involving complex formation with phosphotungstic–phosphomolybdic reagents, and total phenolics were measured using the Folin–Ciocalteu method, expressed in gallic acid equivalents. Cardiac glycosides were quantified using the Keller–Killiani assay, which detects the deoxy-sugar moiety through colourimetric reaction with ferric chloride and concentrated sulfuric acid. All analyses were performed in triplicate.

Antioxidant activity

The antioxidant activity of the plant extract was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, as described by Baliyan et al. (2022) with slight modifications. A methanolic solution of DPPH (0.1 mM) was prepared, and an aliquot containing 100 µg/ml of each extract was mixed with 2 mL of the DPPH solution. The mixture was incubated in the dark at room temperature for 30 minutes, after which the absorbance was measured at 517 nm using a UV-Visible spectrophotometer. The percentage inhibition of DPPH radicals was calculated.

Insecticidal Activity

The insecticidal activities, including adult mortality, repellency, and inhibition of adult emergence, were evaluated following the method of Dyte & Foster (1973), with slight modifications. Methanolic extracts of *Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum* were prepared at concentrations of 2%, 5%, and 10%. These concentration levels were selected based on preliminary range-finding tests to evaluate relative insecticidal potency rather than for LC₅₀ determination. For each treatment, maize grains were disinfested by heating at 60 °C for 4 hours in a hot-air oven to eliminate any pre-existing insect life stages. They were then allowed to cool to room temperature before use.

Mortality rate

For each treatment, 50 g of disinfested maize grains was weighed into clean plastic containers, and 5.0 mL of the respective extract solution was applied. The grains were thoroughly mixed to ensure uniform

coating and air-dried to allow complete methanol evaporation, while methanol-treated grains served as the control. Ten adult *Sitophilus zeamais* were then introduced into each container, which was covered with muslin cloth to permit aeration and maintained under ambient laboratory conditions (27 ± 2 °C; 70 ± 5% RH). Mortality was assessed by recording the number of dead insects at 12, 24, and 36 h post-treatment, and percentage mortality was calculated relative to the control. All treatments and analyses were performed in triplicate. Following mortality evaluation, repellency assays were conducted to assess the behavioural avoidance response of the insects to the treated grains.

Percentage repellency

Repellency was evaluated using the area preference method. Two equal portions of clean maize grains (25 g each) were placed on opposite sides of a rectangular plastic tray (10 × 6 cm). One portion was treated with 2.5 mL of the plant extract solution (treatment zone), while the other portion was treated with 2.5 mL of methanol only (control zone). The tray was air-dried for 10 minutes to allow the methanol to evaporate. Ten adult *Sitophilus zeamais* were then released along the central line separating the two grain zones (approximately 1 cm boundary) to allow free movement between the treated and untreated grains. The number of insects present in each zone was recorded at 0, 1, 4, 7, and 10 days. The repellency percentage was calculated relative to the control. All treatments and analyses were performed in triplicate. Following repellency testing, adult emergence inhibition assays were conducted to assess the long-term reproductive effects of the extracts on progeny development.

Emergence inhibition

For adult emergence inhibition, five pairs (five males and five females) of *Sitophilus zeamais* adults were used for each treatment. The adults were sexed based on rostrum morphology and size differences, where females possess a longer and more slender rostrum compared to males. Each pair was introduced into 50 g of treated maize grains and allowed to mate and oviposit for 7 days. Afterwards, all parental adults were carefully removed using a fine brush. The grains were then stored for 40 days under ambient laboratory conditions (27 ± 2 °C; 70 ± 5% RH) to allow F₁ progeny development. The 40-day duration was selected based on the average developmental period of *S. zeamais* from egg to adult emergence under similar

temperature and humidity conditions. During the storage period, the grains were periodically inspected every 5 days to monitor for signs of larval tunneling, pupal cases, or early adult emergence. After the 40 days, the number of F₁ adults that successfully emerged was recorded for each treatment at 12, 24, and 36 h post-emergence, and the percentage inhibition of adult emergence was calculated relative to the control. All treatments and analyses were performed in triplicate.

Statistical analysis

The experimental data were analysed using SPSS version 26. One-way ANOVA was used to determine differences among treatment groups, followed by Duncan's Multiple Range Test (DMRT) for post-hoc comparisons. Results were expressed as mean \pm SEM ($n=3$), where n represents three independent biological replicates for each treatment group. Statistical significance was set at $p < 0.05$.

Results and Discussion

This study evaluated the insecticidal potential of methanolic extracts from *Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum* against *Sitophilus zeamais*, a major pest of stored maize. The assessment focused on adult mortality, repellency, and inhibition of adult emergence at different extract concentrations. Phytochemical and antioxidant analyses were also conducted to identify the bioactive compounds and radical scavenging properties that may contribute to the observed insecticidal effects. Overall, the extracts demonstrated varying degrees of efficacy, suggesting their potential as natural alternatives to synthetic grain protectants.

Phytochemical compositions

The phytochemical profiles of *Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum* extracts (as shown in Figure 1) revealed distinct variations in secondary metabolite content, which serve as key indicators of their potential insecticidal efficacy.

B. pinnatum exhibited the highest alkaloid concentration (7.85 mg/100 g) along with considerable levels of cardiac glycosides (6.96 mg/100 g) and phenolics (5.29 mg/100 g). Alkaloids are widely recognised for their neurotoxic effects on insect pests, primarily through interference with neural transmission and enzyme activity. Compounds such as nicotine and related alkaloids act on insect nicotinic

acetylcholine receptors (nAChRs), leading to overstimulation and paralysis. In contrast, others, including berberine and sanguinarine, inhibit acetylcholinesterase and disrupt cholinergic signalling (Costas-Ferreira & Faro, 2021). Similarly, tropane alkaloids, such as atropine, commonly found in Solanaceae species, can interfere with neural pathways and inhibit insect growth (Gajger & Dar, 2021). Cardiac glycosides may further contribute to insecticidal activity by disrupting ion balance through inhibition of the Na⁺/K⁺-ATPase enzyme, thereby affecting metabolic and physiological processes. Interestingly, some insect species have adapted to tolerate or even sequester these compounds for their own defence (Bejček et al., 2021).

A. melegueta demonstrated the highest concentration of phenols (10.65 mg/100 g) and tannins (3.83 mg/100 g), along with notable amounts of alkaloids (6.92 mg/100 g) and cardiac glycosides (5.39 mg/100 g). Tannins and phenolic compounds exhibit notable antioxidant effects, contributing to plant defence systems by deterring herbivores and inhibiting pathogen activity (Akbar et al., 2023). Their high concentration in *A. melegueta* suggests a strong potential for both antioxidant and insecticidal applications, particularly via oxidative stress pathways in insect physiology (Mounisha et al., 2024).

P. tricuspidatus contained the highest cardiac glycoside content (8.31 mg/100 g) and significant flavonoid levels (3.90 mg/100 g). Flavonoids are known to interfere with insect moulting hormones and midgut enzymes, thereby reducing survivability and growth (Riddick, 2024). The combined presence of flavonoids and cardiac glycosides in *P. tricuspidatus* may provide a synergistic mode of action, enhancing its insecticidal potential (Boate & Abalis, 2020).

The distinct phytochemical strengths of each extract support their roles as eco-friendly botanical insecticides. The observed differences suggest that *A. melegueta* may potentially excel in inducing oxidative damage, *B. pinnatum* in neurotoxicity, and *P. tricuspidatus* in hormonal disruption of insect development (Darrag et al., 2022). These variations emphasise the complementary nature of their bioactive profiles and their potential value as eco-friendly botanical insecticides within integrated pest management systems.

DPPH antioxidant activity

The antioxidant capacities of methanolic extracts from *Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum* were assessed using the

DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay, with the results presented in Figure 2. The analysis revealed significant variation in antioxidant activity among the samples. *A. melegueta* exhibited the highest DPPH scavenging activity (74.13 %) at 100 µg/ml, followed by *B. pinnatum*, while *P. tricuspидatus* showed the lowest activity at 58.94 %. This result highlights varying capacities of the extracts to neutralise free radicals, indicating their potential in mitigating oxidative stress (Zhang & Feng, 2018). The superior antioxidant activity observed in *A. melegueta* can be attributed to its high levels of polyphenolic compounds, including phenols, flavonoids, and tannins (as shown in Figure 1). These compounds are known for their radical scavenging

mechanisms, primarily through hydrogen donation and metal chelation (Khan et al., 2024). Their presence enhances the ability of the plant extracts to counteract oxidative damage, which is not only beneficial for health applications but may also support insecticidal effectiveness. Insects such as *Sitophilus zeamais* are susceptible to oxidative imbalance, and certain plant antioxidants may exhibit secondary pro-oxidant effects under stress conditions, thereby intensifying oxidative damage, disrupting physiological functions, and contributing to mortality (Salim et al., 2024). Additionally, antioxidants may stabilise active phytochemicals, thereby enhancing the stability and shelf life of botanical insecticides.

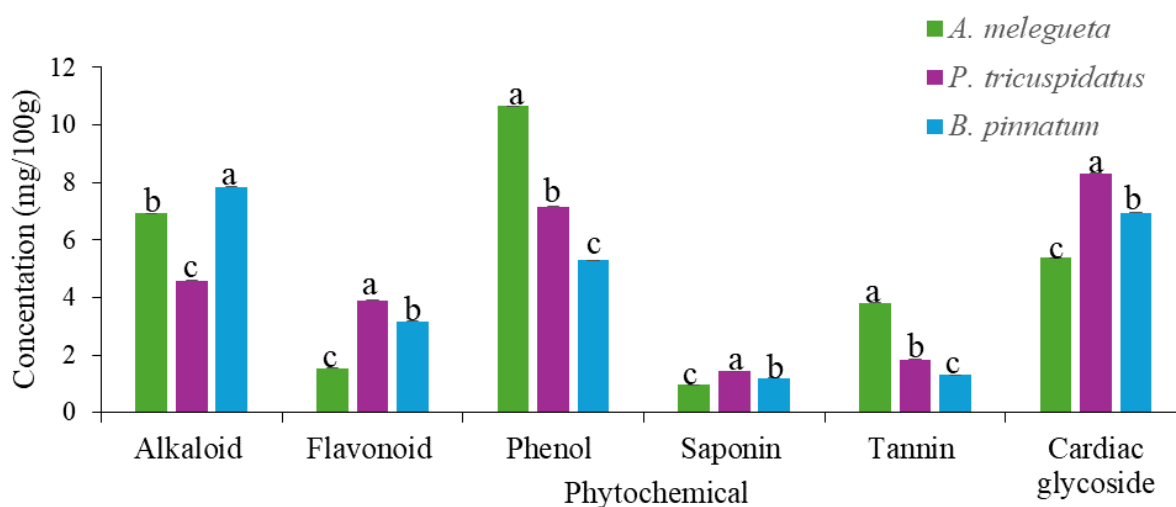


Figure 1: The concentration of phytochemicals in the extracts. Mean±SEM (n=3). Means for each treatment in the same column with the same superscripts are not significantly different (p<0.05)

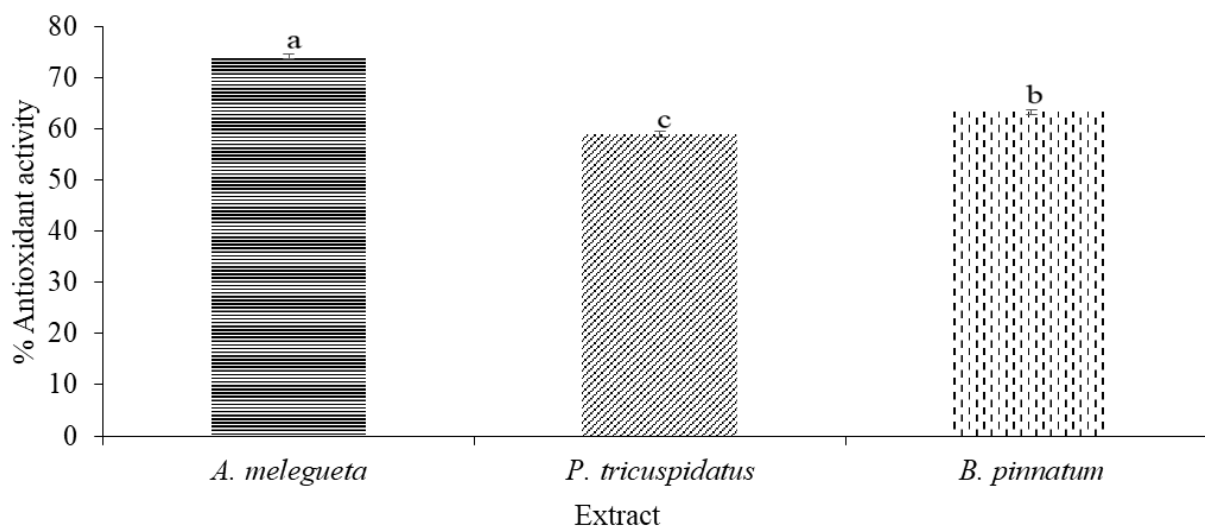


Figure 2: Percentage of antioxidant activity of the extracts. Mean±SE (n=3). Means for each treatment in the same column with the same superscripts are not significantly different (p<0.05, Duncan’s multiple range test).

The observed correlation between antioxidant activity and insecticidal potency supports the role of *A. melegueta* as a promising candidate in eco-friendly pest control. Similarly, although less potent, the antioxidant activity in *B. pinnatum* and *P.*

tricuspidatus suggests supplementary bioactivity that may contribute to their overall effectiveness in integrated pest management systems (Ejiofor et al., 2023). The findings affirm that antioxidant capacity may play a pivotal role in enhancing the insecticidal and protective properties of plant-based extracts.

Mortality rates

The insecticidal efficacy of methanolic extracts from *Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum* against *Sitophilus zeamais* was concentration- and time-dependent, with all extracts showing varying degrees of mortality over the 36-h exposure period (Table 1). Some treatments, particularly *A. melegueta* at 2% after 36 h (50.00%), exhibited relatively high standard errors, likely reflecting biological variability among insects and minor procedural differences. Despite this, mortality trends remained consistent across treatments, confirming the overall toxic effect of the extracts. *P. tricuspidatus* produced the highest mortality at 2% after 36 h (76.67%), suggesting a strong and rapid mode of action, possibly due to its high flavonoid and cardiac glycoside content, which can interfere with

insect hormonal and digestive processes (Boate & Abalis, 2020; Francis et al., 2024).

At 5%, *A. melegueta* and *B. pinnatum* achieved peak mortalities of 80.00% and 83.33%, respectively. The strong efficacy of *A. melegueta* may be linked to its richness in phenols, alkaloids, and tannins, compounds known to disrupt insect neuromuscular activity and induce oxidative stress (Khan et al., 2024; Ejiofor et al., 2023). Although *P. tricuspidatus* showed rapid early mortality (76.67% at 12 h), the final count after 36 h declined slightly (56.67%), possibly due to detoxification or degradation of active constituents. Conversely, *B. pinnatum* demonstrated slower but sustained activity, suggesting delayed biochemical interactions that could support longer-term pest suppression (Masih & Ahmad, 2019).

At 10%, all three extracts recorded moderate but comparable mortalities (56–60%) after 36 h, indicating that higher doses did not significantly enhance insecticidal performance. This plateau effect could be attributed to repellent behaviour or partial degradation of active compounds at higher concentrations, which may have reduced insect contact or bioavailability.

The 0% mortality in controls confirmed that effects were extract-dependent.

Table 1: Percentage mortality of *Sitophilus zeamais* exposed to methanolic extracts of *Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum* at different concentrations and exposure times.

| Concentration | Treatments | Exposure time | | |
|---------------|-----------------------------|---------------------------|---------------------------|---------------------------|
| | | 12 hrs | 24hrs | 36hrs |
| 2% | <i>A. melegueta</i> (%) | 63.33±12.02 ^{ab} | 63.33±3.333 ^b | 50.00±10.000 ^b |
| | <i>P. tricuspidatus</i> (%) | 66.67±6.67 ^a | 50.00±5.774 ^{ab} | 76.67±3.333 ^a |
| | <i>B. pinnatum</i> (%) | 33.33±3.33 ^b | 46.67±3.333 ^a | 56.67±13.333 ^b |
| 5% | <i>A. melegueta</i> (%) | 56.67±14.53 ^a | 60.00±11.547 ^a | 80.00±0.000 ^{ab} |
| | <i>P. tricuspidatus</i> (%) | 63.33±17.64 ^{ab} | 76.67±13.333 ^a | 66.67±6.667 ^a |
| | <i>B. pinnatum</i> (%) | 66.67±3.33 ^a | 66.67±3.333 ^a | 83.33±3.333 ^b |
| 10% | <i>A. melegueta</i> (%) | 30.00±10.00 ^c | 36.67±6.667 ^a | 60.00±5.774 ^a |
| | <i>P. tricuspidatus</i> (%) | 76.67±8.82 ^a | 60.00±5.774 ^b | 56.67±6.667 ^a |
| | <i>B. pinnatum</i> (%) | 53.33±16.67 ^b | 63.33±3.333 ^b | 60.00±5.774 ^a |
| 0% | Control | 0.00±0.00 | | |

Mean±SEM (n=3). Means for each treatment in the same column with the same superscripts are not significantly different ($p < 0.05$, Duncan's multiple range test).

The progressive increase in mortality over time indicates cumulative toxicity, especially in phenolic- and alkaloid-rich extracts such as *A. melegueta* and *B. pinnatum* (Mounisha et al., 2024). IC₅₀ values were not determined because only three fixed concentrations were tested; therefore, results are presented as comparative potency indicators rather than quantitative lethal thresholds. Future studies should

employ broader dose ranges and include standard insecticides as positive controls for benchmarking. Overall, *P. tricuspidatus* exhibited rapid action at lower concentrations, while *A. melegueta* and *B. pinnatum* maintained prolonged efficacy at higher concentrations, underscoring their promise as eco-friendly protectants for stored maize.

Repellent efficacy

The repellency efficacy of the methanolic extracts of *Aframomum melegueta*, *Pterocelastrus tricuspidatus* and *Bryophyllum pinnatum* against *Sitophilus zeamais* is presented in Table 2. Repellency was assessed at proximity (1 cm) using extract concentrations of 2%, 5%, and 10% over 10 days. The results showed that all three extracts significantly reduced the presence of insects compared to the untreated control ($p < 0.05$), indicating effective repellent activity.

Untreated controls consistently recorded the highest number of *S. zeamais* (ranging from 3.67 to 5.00 insects), reaffirming the absence of natural repellency. In contrast, treated groups exhibited a concentration and time-dependent decline in insect count. Notably, at 2%, *P. tricuspidatus* showed the most pronounced repellency on Day 7 (0.33 insect), outperforming both *A. melegueta* and *B. pinnatum*. Although the repellency of *B. pinnatum* decreased slightly by Day 10, its effect remained significant compared to the control.

At 5%, all extracts demonstrated enhanced repellent activity. *A. melegueta* exhibited particularly stable repellency (1.00–2.00 insects), while *P. tricuspidatus* and *B. pinnatum* also maintained moderate repellency

(1.33–2.67 insects), with significant differences observed, especially on Days 1 and 4. The 10% concentration produced the strongest repellency across all extracts. Both *A. melegueta* and *P. tricuspidatus* recorded the lowest insect counts (0.33 on Day 1), indicating immediate and potent repellent effects sustained throughout the exposure period. Although *B. pinnatum* also showed strong repellency at this level, its efficacy was slightly more variable.

These findings highlight the potential of plant-based repellents in integrated pest management (IPM), particularly due to their bioactive constituents such as alkaloids, flavonoids, and cardiac glycosides, which are known to deter insect pests by disrupting their olfactory or neurological pathways (Qasim et al., 2024). The observed repellency at close range further supports the presence of potent bioactive compounds capable of immediate behavioural effects on *S. zeamais*, consistent with previous studies that highlight the efficacy of essential oils and plant-derived compounds in pest control (Wei et al., 2025). Among the tested plants, *A. melegueta* and *P. tricuspidatus* emerged as the most effective, underscoring their promise as eco-friendly protectants for stored maize.

Table 2: Comparative repellency of *Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum* against *Sitophilus zeamais* at 1 cm distance from treatment zones.

| Concentration | Treatment | Day 0 | Day 1 | Day 4 | Day 7 | Day 10 |
|---------------|-------------------------|------------------------|-------------------------|------------------------|-------------------------|-------------------------|
| 2% | Control (Untreated) | 5.00±0.58 ^a | 4.67±0.33 ^a | 3.67±0.33 ^a | 5.00±0.58 ^a | 4.00±0.58 ^a |
| | <i>A. melegueta</i> | 1.00±0.58 ^c | 1.33±0.33 ^c | 2.33±0.33 ^b | 1.00±0.58 ^b | 2.00±0.58 ^b |
| | <i>P. tricuspidatus</i> | 1.00±0.58 ^c | 2.67±0.88 ^b | 1.00±0.58 ^c | 0.33±0.33 ^c | 1.33±0.67 ^c |
| | <i>B. pinnatum</i> | 3.33±0.88 ^b | 2.00±0.58 ^{bc} | 1.33±0.33 ^c | 1.33±0.67 ^b | 2.33±0.33 ^b |
| 5% | Control (Untreated) | 5.00±0.58 ^a | 4.67±0.33 ^a | 3.67±0.33 ^a | 5.00±0.58 ^a | 4.00±0.58 ^a |
| | <i>A. melegueta</i> | 1.00±0.58 ^c | 1.67±0.88 ^c | 1.67±0.33 ^c | 1.67±0.33 ^b | 2.00±0.58 ^b |
| | <i>P. tricuspidatus</i> | 2.0±0.58 ^b | 1.67±0.88 ^c | 1.67±0.88 ^c | 1.33±0.33 ^{bc} | 1.33±0.88 ^{bc} |
| | <i>B. pinnatum</i> | 2.33±0.88 ^b | 2.67±0.33 ^b | 2.67±0.33 ^b | 1.33±0.33 ^{bc} | 1.33±0.67 ^{bc} |
| 10% | Control (Untreated) | 5.00±0.58 ^a | 4.67±0.33 ^a | 3.67±0.33 ^a | 5.00±0.58 ^a | 4.00±0.58 ^a |
| | <i>A. melegueta</i> | 2.00±0.58 ^b | 0.33±0.33 ^c | 0.67±0.67 ^c | 1.33±0.67 ^b | 0.33±0.33 ^c |
| | <i>P. tricuspidatus</i> | 0.67±0.33 ^c | 0.33±0.33 ^c | 1.00±0.58 ^c | 0.67±0.67 ^c | 2.33±0.67 ^b |
| | <i>B. pinnatum</i> | 2.67±0.33 ^b | 0.67±0.67 ^{bc} | 1.67±0.67 ^b | 1.00±0.58 ^b | 1.00±0.57 ^{bc} |

Mean±SEM (n=3). Means for each treatment in the same column with the same superscripts are not significantly different ($p < 0.05$, Duncan's multiple range test).

Emergence inhibition

The emergence inhibition of *Sitophilus zeamais* following exposure to different concentrations of plant extracts over time is presented in Table 3. All the tested extracts (*Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum*) significantly reduced adult emergence compared to the untreated control, which recorded a total emergence rate of 42.67% after 36 h.

At 2%, all extracts exhibited varying levels of emergence suppression. *B. pinnatum* showed relatively lower inhibition (8.33%, 0.67%, and 0.67% at 12, 24, and 36 h, respectively) compared to *A. melegueta* and *P. tricuspidatus*. *A. melegueta* extract significantly suppressed the emergence of *S. zeamais* within 12 h (2.00%) and maintained strong inhibitory activity at 24 h (0.67%). However, emergence slightly increased after 36 h (9.67%), suggesting a decline in potency

over time. This trend suggests that the effectiveness of *A. melegueta* is time-dependent, exhibiting strong early suppression that gradually diminishes over time. Although some variation was observed, the differences were not statistically significant ($p > 0.05$).

At 5% concentration, the emergence rate further decreased. *B. pinnatum* maintained consistently low emergence values (1.67%, 1.67%, and 2.00% at 12, 24, and 36 h, respectively), indicating stronger inhibition than the other extracts. *P. tricuspidatus* also performed comparably well, particularly at 12 h (1.33%), where its inhibitory effect differed significantly from that of *A. melegueta*.

The most pronounced suppression of *S. zeamais* emergence occurred at 10% concentration. *P. tricuspidatus* completely inhibited emergence at 12 h (0.00%), and maintained near-total inhibition at 24 and 36 h (0.33% and 1.33%, respectively). Similarly, *A. melegueta* and *B. pinnatum* achieved near-complete suppression at 24 h (2.33% and 0.00%, respectively). These findings suggest a strong concentration-

dependent effect of the extracts, with 10% formulations demonstrating the highest efficacy. Overall, emergence inhibition increased with concentration across all extracts. These findings align with previous reports by Ndebugri et al. (2024) and Boate & Abalis (2020), which highlighted the insecticidal potential of plant-derived substances against stored-grain pests. The inhibition observed may be attributed to the bioactive constituents of the tested plant materials, which likely exerted ovicidal or larvicidal action that prevents adult emergence (Chaudhari et al., 2021). The high potency of *P. tricuspidatus* at 10% concentration, especially after short exposure times, highlights its potential as a promising botanical protectant for stored products. Therefore, the study findings suggest that *A. melegueta*, *P. tricuspidatus*, and *B. pinnatum* extracts, particularly at higher concentrations, could serve as effective alternatives to synthetic insecticides in managing *S. zeamais* infestations.

Table 3: Emergence rate of *Sitophilus zeamais* following exposure to *Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum* extracts.

| Concentration | Samples | Exposure time | | |
|---------------|-----------------------------|-------------------------|------------------------|-------------------------|
| | | 12 h | 24 h | 36 h |
| 2% | <i>A. melegueta</i> (%) | 2.00±1.00 ^a | 0.67±0.33 ^a | 9.67±3.69 ^a |
| | <i>P. tricuspidatus</i> (%) | 4.00±1.53 ^a | 6.33±4.84 ^a | 1.67±0.88 ^a |
| | <i>B. pinnatum</i> (%) | 8.33±2.73 ^a | 0.67±0.33 ^a | 0.67±0.67 ^a |
| 5% | <i>A. melegueta</i> (%) | 4.67±2.33 ^a | 3.00±1.00 ^a | 13.33±5.70 ^a |
| | <i>P. tricuspidatus</i> (%) | 1.33±0.67 ^{ab} | 3.00±1.53 ^a | 2.33±0.67 ^a |
| | <i>B. pinnatum</i> (%) | 1.67±1.67 ^b | 1.67±1.20 ^a | 2.00±1.00 ^a |
| 10% | <i>A. melegueta</i> (%) | 1.00±0.59 ^{ab} | 2.33±0.33 ^a | 0.67±0.67 ^b |
| | <i>P. tricuspidatus</i> (%) | 0.00±0.00 ^b | 0.33±0.33 ^b | 1.33±0.33 ^a |
| | <i>B. pinnatum</i> (%) | 3.00±3.00 ^a | 0.00±0.00 ^b | 2.00±1.16 ^a |
| 0% | Control | 42.67±4.91 | | |

Mean±SEM (n=3). Means for each treatment in the same column with the same superscripts are not significantly different ($p < 0.05$, Duncan's multiple range test).

Conclusion

This study highlights the insecticidal potential of *Aframomum melegueta*, *Pterocelastrus tricuspidatus*, and *Bryophyllum pinnatum* against *Sitophilus zeamais*, a major pest of stored maize. Phytochemical analysis confirmed the presence of bioactive compounds, including alkaloids, flavonoids, tannins, and saponins, which contribute to the insecticidal efficacy. The observed antioxidant properties further suggest that redox-active constituents may enhance insect mortality by inducing oxidative stress and disrupting cellular homeostasis.

Bioassay results demonstrated significant mortality across all treatments, with *B. pinnatum* showing the

highest mortality (83.33% at 5% after 36 h), while *P. tricuspidatus* exhibited superior efficacy even at lower concentration (76.67% at 2% at 36 h), indicating concentration-dependent potency among the extracts. These findings suggest that the tested plant extracts could serve as effective botanical alternatives to synthetic insecticides in postharvest pest management. Their natural composition suggests potential environmental friendliness and lower human toxicity; however, these assumptions require further validation through targeted toxicity assessments on non-target organisms and human safety evaluations. Future studies should explore alternative extraction solvents and techniques to identify methods that maximise the

yield and potency of bioactive compounds. In addition, investigations into formulation stability, application methods, and residual efficacy under storage conditions are recommended, alongside the identification of active compounds, assessment of possible synergistic effects among combined extracts, and evaluation of their toxicity to non-target and beneficial insects. Furthermore, evaluating the quality of treated grain, including germination rates, nutritional composition, sensory properties, and extract residue levels, is essential before recommending these extracts for commercial use.

Acknowledgement: The authors sincerely express their gratitude to the Executive Director and the entire management of the Nigerian Stored Products Research Institute, Nigeria, for their financial support, which made this study possible.

Funding statement: This research was funded by the Nigerian Stored Products Research Institute, Nigeria (Grant No. ERGP 30111244/NSPRI/2023/7).

Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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