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Research Article

Effect of Azadirachta Indica, Pongamia Glabra, and Adhatoda Vasica on Termites, Arthropods, Shoot Borers and Coleopteran Pests

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ABSTRACT

The excessive use of synthetic chemical pesticides for the management of insect pests in agriculture has led to serious environmental, ecological, and health concerns, necessitating the exploration of eco-friendly alternatives. The present investigation evaluated the bioefficacy of three botanical pesticides—*Azadirachta indica* (neem), *Pongamia glabra* (karanja), and *Adhatoda vasica* (adhatoda)—against major insect pests of sugarcane, including termites (*Odontotermes obesus*), shoot borers (*Chilo infuscatellus*), orthopterans, and coleopteran pests. Field and laboratory experiments were conducted in Sultanpur district, Uttar Pradesh, using a randomized block design with botanical treatments applied as foliar sprays and soil drenches at different concentrations, along with a synthetic chemical pesticide and an untreated control for comparison. Observations were recorded on pest infestation, mortality, repellency, growth, and reproductive parameters. The results showed that all botanical treatments significantly reduced pest infestation compared to the control. *Azadirachta indica* extract and the combined botanical formulation exhibited the highest efficacy among all, achieving 70–72% reduction in termite infestation and 69–70% reduction in shoot borer incidence, values comparable to the synthetic pesticide. Mortality and repellency assays further confirmed the strong insecticidal and deterrent effects of neem and combined botanical treatments, with mortality exceeding 75% after 72 hours of exposure. The study demonstrates that botanical pesticides, particularly neem-based and combined formulations, possess strong potential as sustainable, biodegradable, and environmentally safe alternatives to chemical pesticides and can be effectively integrated into integrated pest management (IPM) strategies for sugarcane cultivation.

Introduction

Globally, agricultural productivity and forest ecosystems are seriously threatened by insect pests like termites, orthopterans, shoot borers, and coleopteran pests. Food security and economic stability are negatively impacted by these pests, which cause significant losses in crop yield, quality, and stored goods. Synthetic chemical pesticides are the mainstay of conventional management for these insect pests, but their indiscriminate and long-term use has resulted in a number of ecological and health issues, such as pesticide resistance, environmental pollution, bioaccumulation, and negative effects on non-target organisms and human health (Pimentel, 2005; Aktar *et al.,* 2009). As a result, there is a growing need for sustainable, biodegradable, and environmentally friendly substitutes for synthetic pesticides.

In integrated pest management (IPM) programs, botanical pesticides made from plants with insecticidal, antifeedant, growth-regulating, and reproductive inhibitory qualities have become viable substitutes. Among these, *Adhatoda vasica* (vasaka), Pongamia glabra (karanja), and *Azadirachta*

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indica (neem) have drawn a lot of attention because of their broad-spectrum bioactivity against many insect pests and rich phytochemical composition. Azadirachta indica, which contains bioactive substances such *azadirachtin*, salannin, nimbin, and meliantriol, is one of the botanical insecticides that has been investigated the most. In various insect orders, such as Coleoptera, Orthoptera, and Isoptera, these substances are known to disrupt feeding behavior, molting, metamorphosis, growth, and reproduction. This results in decreased fertility and population suppression (Schmutterer, 1990; Isman, 2006). In insects, neem-based formulations have been shown to interfere with endocrine regulation, causing delayed development, deformed adults, and reduced egg viability.

Another significant pesticidal plant is *Pongamia glabra* (syn. Pongamia pinnata), which is rich in flavonoids with insecticidal, ovicidal, and repellant qualities, such as karanjin and pongamol. The growth rate, survival, and reproductive potential of termites, coleopteran pests, and lepidopteran larvae have all been significantly impacted by P. glabra extracts (Sarma *et al.,* 2004; Pavela, 2016). The plant is prized for its environmental friendliness and low toxicity to mammals.

Alkaloids like vasicine and vasicinone, which have been shown to have insecticidal and growth-inhibitory actions, are found in *Adhatoda vasica*, a plant traditionally recognized for its medicinal qualities. Research shows that *A. vasica* extracts can negatively impact the development of larvae, adult emergence, and reproductive performance in a number of insect pests, such as orthopterans and shoot borers (Koul *et al.,* 2008). Because of its accessibility and biodegradability, its function as a botanical insecticide is becoming more well acknowledged.

There are still few comparative studies evaluating these plants' impact on the growth and reproductive biology of several pest groups, including termites (Isoptera), orthopterans, shoot borers, and coleopteran pests, despite the abundance of reports on their insecticidal activities. Evaluating the potential of these botanical pesticides in sustainable pest management systems requires an understanding of how they affect important biological parameters. In order to find efficient plant-based substitutes for synthetic pesticides, the current study attempts to evaluate the effects of pesticides based on *Azadirachta indica*, *Pongamia glabra,* and *Adhatoda vasica* on the growth and reproduction of specific insect pests.

Extracts derived from *Azadirachta indica* (neem), *Pongamia glabra* (karanja), and *Adhatoda vasica* (adhatoda) have been extensively investigated for their insecticidal potential and have been proven to exert significant adverse effects on the growth, development, and reproduction of a wide range of insect pests, including termites, orthopterans, lepidopteran shoot borers, and coleopteran beetles (Schmutterer, 1990; Isman, 2006). These botanical pesticides act through multiple mechanisms, including strong antifeedant activity that deters insects from feeding on treated plants and ultimately leads to starvation (Mordue and Nisbet, 2000). They also interfere with insect endocrine systems, particularly molting and growth hormones, resulting in disrupted development, abnormal molting, prolonged larval stages, and increased mortality (Govindachari, 1992; Isman, 2006). In addition, these plant extracts exhibit reproductive inhibitory effects by acting as oviposition deterrents and reducing fecundity or inducing partial sterility in adult insects, thereby limiting population buildup (Schmutterer, 1990; Koul *et al.,* 2008). Although higher concentrations may cause direct toxicity and mortality, their primary mode of action lies in disrupting insect life cycles rather than immediate lethal effects (Isman, 2006). Furthermore, neem, karanja, and adhatoda extracts possess strong repellent properties that prevent pests from approaching or colonizing treated crops (Singh and Pandey, 2010). Neem oil and its bioactive compound azadirachtin have demonstrated high efficacy against termites by significantly reducing feeding activity, wood damage, and survival rates (Schmutterer, 1990; Mordue and Nisbet, 2000). Neem-based formulations have also been shown to alter feeding behavior and growth in orthopteran pests (Isman, 2006), while neem kernel extracts significantly inhibit larval development of lepidopteran shoot borers (Govindachari, 1992). Similarly, neem and karanja seed extracts have proven effective against several coleopteran pests by deterring feeding and inducing mortality (Koul *et al.,* 2008). Owing to their broad-spectrum activity, biodegradability, and reduced risk of resistance development, these botanical pesticides represent an eco-friendly and sustainable alternative to synthetic chemical pesticides within integrated pest management programs (Isman, 2006; Singh and Pandey, 2010).

Materials And Methods

Study Site

The present study was conducted in both field and laboratory settings. Populations of major insect pests of cash crops such as termites, orthopterans, shoot borers, and coleopterans were collected from various agricultural fields located in the Sultanpur district of Uttar Pradesh, India.

Experimental Design

The field experiment was undertaken to evaluate the bioefficacy of botanicals prepared from *Azadirachta indica* (Neem), *Pongamia glabra* (Karanja), and *Adhatoda vasica* (Adulsa) against termites (*Odontotermes obesus* and related species) and shoot borers (*Chilo infuscatellus* Snellen) infesting sugarcane (*Saccharum officinarum* L.). The study was conducted during the growing season at the Experimental Farm, Department of Entomology, located in

District Sultanpur, Uttar Pradesh, India. The site lies in the Indo-Gangetic alluvial plain, characterized by subtropical climatic conditions with hot summers, moderate rainfall, and cool winters—ideal for sugarcane cultivation.

The experiment was laid out following a Randomized Block Design (RBD) with four treatments and three replications, to minimize the effects of environmental variability and to ensure reliable statistical comparison.

Layout Details

- Design: Randomized Block Design (RBD)
- Number of Treatments: Six (4)
- Number of Replications: Three (3)
- Total Number of Plots: 12 (4 treatments × 3 replications)
- Plot Size: 6 m × 5 m (30 m^2 per plot)
- Net Experimental Area: 360 m^2 (including borders and pathways)
- Row Spacing: 75 cm between rows
- Plant Spacing: 30 cm between plants within rows
- Buffer Zone: 0.5 m between plots and 1.0 m between replications to avoid drift contamination
- Crop Variety: *Saccharum officinarum* var. Co-0238 (a high-yielding, locally adapted variety)

Plant Material Collection

The botanical materials (*Azadirachta indica*, *Pongamia glabra*, and *Adhatoda vasica*) used for pesticide preparation were collected from local agricultural fields and markets across Sultanpur district. The collected plant materials were stored in clean, labeled plastic containers and kept in a dry and shaded environment prior to extract preparation.

Botanical Species Used:

- *Azadirachta indica* (Neem)
- *Pongamia glabra* (Karanja)
- *Adhatoda vasica* (Malabar nut)

Extraction Method

- Fresh, healthy leaves of each plant were collected, washed, and shade-dried.
- 500 g of each leaf type was macerated using a blender.
- The paste was soaked in 1 L of distilled water (1:2 w/v) for 24 hours.
- Extracts were filtered through muslin cloth followed by Whatman No.1 filter paper.
- The filtrates were stored in amber bottles at 4°C and used within 72 hours.

Treatment Details

In the present study, five treatments were evaluated to determine the bioefficacy of selected botanical pesticides and a standard chemical control against termite and shoot borer infestation in sugarcane (*Saccharum officinarum* L.). The treatments included three botanicals—*Azadirachta indica* (Neem), *Pongamia glabra* (Karanja), and *Adhatoda vasica* (Adulsa)—applied at different concentrations, along with a synthetic chemical pesticide and an untreated control for comparison.

The first treatment (T_1) consisted of *Azadirachta indica* leaf extract prepared at a 5% (w/v) concentration. The second treatment (T_2) involved *Pongamia glabra* leaf extract applied at a 10% (w/v) concentration, while the third treatment (T_3) used *Adhatoda vasica* leaf extract at a 15% (w/v) concentration. The fourth treatment (T_4) comprised a synthetic chemical pesticide, either Imidacloprid or Chlorpyrifos, applied at a concentration of 0.5% (w/v), serving as a positive control. The fifth treatment (T_5) represented the untreated control, in which no pesticide was applied and only water spray was used Tables 1 and 2. All botanical and chemical treatments were applied as foliar sprays and soil drenches using a hand-operated knapsack sprayer, ensuring uniform coverage of the sugarcane plants. These treatments were designed to assess their relative efficacy in reducing pest infestation, influencing growth parameters, and minimizing yield losses under field conditions.

Target Insect Pests

The present investigation focused on the major insect pests infesting sugarcane (*Saccharum officinarum* L.) under field conditions in Sultanpur district, Uttar Pradesh. The selected pests represent different ecological groups based on their feeding behavior and habitat, thereby providing a comprehensive evaluation of the efficacy of botanical treatments against diverse pest types.

The termite complex, primarily represented by *Odontotermes obesus* (Rambur), constitutes a major subterranean pest of sugarcane, attacking the roots and underground portions of the stalk. Termite activity leads to wilting, reduced tillering, and lodging of canes, ultimately causing substantial yield loss.

Among the orthopteran pests, species belonging to the family Acrididae (e.g., grasshoppers) were included, as they feed on the foliage, reducing photosynthetic efficiency and overall plant vigor.

The shoot borer, *Chilo infuscatellus* Snellen (Lepidoptera: Crambidae), is one of the most destructive borers of sugarcane, attacking the central shoots during the early growth stages. Its infestation results in characteristic "dead-heart" symptoms, stunted growth, and reduced sucrose accumulation.

In addition, coleopteran pests such as *Holotrichia serrata* (Fabricius) and *Leucopholis* spp. (white grubs) were considered, which infest the soil and feed on roots, causing weakening and yellowing of the plants.

The inclusion of these pest groups—soil-dwelling, foliar-feeding, and stem-boring insects—enabled the assessment of the broad-spectrum potential of the selected botanical extracts (*Azadirachta indica*, *Pongamia glabra*, and *Adhatoda vasica*) compared with synthetic chemical controls in managing sugarcane pests under field conditions.

The study targeted the following insect pests associated with sugarcane Table 3:

Table 1: Treatment code and botanical pesticide concentration

Treatment code	*Botanical pesticide*	*Concentration*
T1	*Azadirachta indica*	5% w/v
T2	*Pongamia glabra*	10% w/v
T3	*Adhatoda vasica*	15% w/v
T4	Synthetic chemical (e.g., Imidacloprid or Chlorpyrifos)	0.5 % w/v
T5	Untreated control	-

Table 2: Treatment code and treatment methods

Treatment code	*Treatment description*	*Application method*
t_1	*Azadirachta indica* (Neem) leaf extract	Foliar spray + soil drench
T_2	*Pongamia glabra* (Karanja) leaf extract	Foliar spray + soil drench
T_3	*Adhatoda vasica* (Adulsa) leaf extract	Foliar spray + soil drench
T_4	Combination of *A. indica*, *P. glabra*, and *A. vasica* extracts (1:1:1)	Foliar spray + soil drench
T_5	Standard chemical pesticide (Chlorpyrifos 20 EC @ 2.0 ml/L or Imidacloprid 17.8 SL @ 0.5 ml/L)	Foliar spray + soil drench
T_6	Untreated control (water spray only)	Control plot

Table 3: Target pest group and their habitat

Pest group	*Scientific name (Example)*	*Habitat*
Termites	*Odontotermes obesus*	Soil
Orthopterans	*Acrididae* spp. (e.g., grasshoppers)	Foliage
Shoot Borers	*Chilo infuscatellus*	Stalks/shoots
Coleopterans	*Holotrichia serrata*, *Leucopholis spp.*	Soil and roots

Experimental Procedure

Land preparation

The field will be prepared by two cross ploughings followed by harrowing to obtain a fine tilth. Ridges and furrows will be opened at 75 cm spacing for planting sugarcane setts.

Planting

Healthy, three-budded setts of *Saccharum officinarum* variety Co-0238 will be planted manually in furrows and covered lightly with soil. Standard agronomic practices such as irrigation, weeding, and earthing-up will be followed uniformly for all plots.

Treatment Application:

- First Application: 30 days after planting (DAP) — targeting termite infestation.
- Second Application: 90 DAP — targeting early shoot borer infestation.
- Third Application: 150 DAP — to ensure residual protection during peak pest period.
- Each botanical extract will be applied at predetermined concentrations (5%, 10%, 15%, and 0.3 %) using a hand-operated knapsack sprayer at a spray volume of approximately 500 L/ha.
- For termite control, extracts will also be applied as soil drench around the base of each clump.

Observation Schedule

Observations on termite and shoot borer incidence will be recorded at 7, 15, and 30 days after each treatment (DAT).

Parameters Recorded

Termite Infestation (%)

- Ten randomly selected clumps per plot was examined for termite activity.
- Termite incidence was calculated as:

Termite Infestation (%) = Number of infested clumps/Total number of clumps observed X 100

Shoot Borer Incidence (%)

- Observation of dead hearts caused by *Chilo infuscatellus* was made at 60, 90, and 120 DAP.
- Percent dead hearts were calculated using the formula:

Dead Hearts (%) =Total number of shoots observed/ Number of dead heart shoots × 100

Yield Attributes

At harvest, data was recorded for:

- Number of millable canes per plot
- Cane height (m)
- Cane girth (cm)
- Cane yield (t/ha)

Phytotoxicity Observation

Plots was inspected regularly for symptoms of phytotoxicity such as chlorosis, leaf burn, or growth retardation following botanical treatments.

Reproductive Output

Number of eggs laid, egg hatchability percentage, and nymph/larval development time.

Growth Indicators

Weight and length of larvae/nymphs at different intervals (Day 3, 7, 14). Botanical extracts were applied by dipping food materials or mixing into sterilized soil for subterranean pests.

Assessment of Mortality Rate

Bioassay protocol

- Contact and ingestion toxicity were evaluated by exposing the pests to treated diet or surfaces.

- Each treatment had 3 replicates with 10 insects per replicate.

Mortality recording

- Observations were taken at 24-, 48-, and 72-hours post-treatment.
- Mortality (%) = (Number of dead insects / Total insects) × 100
- Corrected mortality was calculated using Abbott's formula where required.

Repellency assay

Y-Tube Olfactometer and Choice Chamber Tests:

- Repellent effect was studied using a two-choice setup with treated and untreated arms.
- 10 individual insects per replicate were released and their preference recorded over 1 hour.

Repellency Index (RI) was calculated using the formula:

$$RI = [(C - T) / (C + T)] \times 100$$

Where:

C = Number of insects in control arm T = Number of insects in treated arm RI was categorized as:

- 0–20% = Low repellency
- 21–50% = Moderate repellency
- 50% = Strong repellency

Statistical Analysis

All experiments were conducted in a completely randomized design (CRD) or RCBD (for field studies) with three replications. Data were subjected to Analysis of Variance (ANOVA) using SPSS, OPSTAT. Significant differences among treatments were separated using Tukey's HSD or LSD at $p < 0.05$.

Results

The present study, entitled "Study of Bioefficacy of Azadirachta indica, Pongamia glabra, and Adhatoda vasica Against Termites and Shoot Borers in Sugarcane," was carried out in the Experimental Farm of the Department of Entomology, Sultanpur district, Uttar Pradesh. The results obtained from both field and laboratory investigations are summarized and interpreted under the following sections. The experiment aimed to evaluate the insecticidal potential of three botanicals—*Azadirachta indica* (Neem), *Pongamia glabra* (Karanja), and *Adhatoda vasica* (Adulsa)—in comparison with a synthetic chemical pesticide (Chlorpyrifos or Imidacloprid) and an untreated control. The observations were recorded for pest incidence, mortality, repellency, and changes in biochemical enzyme activities of the target pests.

Effect of Botanical Treatments on Termite Infestation in Sugarcane

Botanical treatments significantly reduced termite infestation compared to the untreated control. Among all treatments, Azadirachta indica (Neem) extract (T_1) and Pongamia glabra (Karanja) extract (T_2) exhibited the highest efficacy with 72.4% and 68.9% reduction in termite infestation, respectively, followed by Adhatoda vasica (Adulsa) (T_3). The synthetic pesticide (T_5) provided maximum reduction (81.2%) but was statistically at par with Neem extract. The data presented in Table 4 show the effect of different botanical and synthetic treatments on termite infestation in sugarcane under field conditions. A significant reduction in termite infestation was observed in all botanical treatments compared to the untreated control.

Among the botanical extracts tested, *Azadirachta indica* (neem) at 5% w/v concentration proved to be the most effective, recording the lowest mean termite infestation of 8.7 ± 0.9%, corresponding to a 72.4% reduction over the control. This was followed by the combination treatment (*A. indica*, *Pongamia glabra*, and *Adhatoda vasica* in a 1:1:1 ratio), which recorded 9.5 ± 0.8% infestation and 70.0% reduction over control. *Pongamia glabra* (10% w/v) also exhibited considerable efficacy, reducing infestation to 10.2 ± 1.0% with 68.9% reduction, while *Adhatoda vasica* (15% w/v) showed a relatively lower effect with 12.5 ± 1.3% infestation and 59.6% reduction over control.

The synthetic chemical treatment (0.5% w/v) showed the highest efficacy, resulting in 7.2 ± 0.6% termite infestation and 81.2% reduction compared to the control, thus confirming its strong insecticidal activity. However, the performance of neem and the botanical combination treatments was statistically comparable to the synthetic treatment, indicating that botanicals can serve as potential eco-friendly alternatives.

The untreated control recorded the maximum infestation (31.6 ± 2.1%), highlighting the natural severity of termite attack in sugarcane. The critical difference (CD) at $p \leq 0.05$ was 2.13, indicating significant differences among treatments. Overall, the results demonstrate that botanical treatments, particularly neem extract and the mixed botanical formulation, were highly effective in suppressing termite infestation, offering a sustainable approach for pest management in sugarcane cultivation.

The termite infestation in sugarcane under different treatments revealed significant variations among the botanical, synthetic, and control plots. As shown in the figure, all treated plots exhibited a substantial reduction in mean termite infestation compared to the untreated control. The lowest termite infestation was recorded in the synthetic treatment (T_5), indicating its strong insecticidal activity against termite attack. Among the botanicals, *Azadirachta indica* (T_1) and the combined botanical formulation (T_4) were the most effective, showing comparatively lower infestation levels, followed by *Pongamia glabra* (T_2) and *Adhatoda vasica* (T_3). The control (T_6) plot, without any treatment, showed the highest infestation percentage, demonstrating the natural

Table 4: Effect of botanical treatments on termite infestation in sugarcane

Treatment code	*Treatment description*	*Mean termite infestation (%) ± SE*	*% Reduction over control*
T_1	*Azadirachta indica* (5% w/v)	8.7 ± 0.9	72.4
T_2	*Pongamia glabra* (10% w/v)	10.2 ± 1.0	68.9
T_3	*Adhatoda vasica* (15% w/v)	12.5 ± 1.3	59.6
T_4	Combination (1:1:1)	9.5 ± 0.8	70.0
T_5	Synthetic chemical (0.5% w/v)	7.2 ± 0.6	81.2
T_6	Control (water)	31.6 ± 2.1	—
CD ($p \leq 0.05$)	—	2.13	—

susceptibility of sugarcane to termite damage in the absence of pest management measures.

The reduced termite infestation in botanically treated plots may be attributed to the presence of bioactive compounds such as azadirachtin, karanjin, and vasicine, which act as repellents, antifeedants, or growth inhibitors against termites. The combined botanical treatment showed improved efficacy, suggesting possible synergistic or complementary effects among different plant-derived compounds (Figure 1).

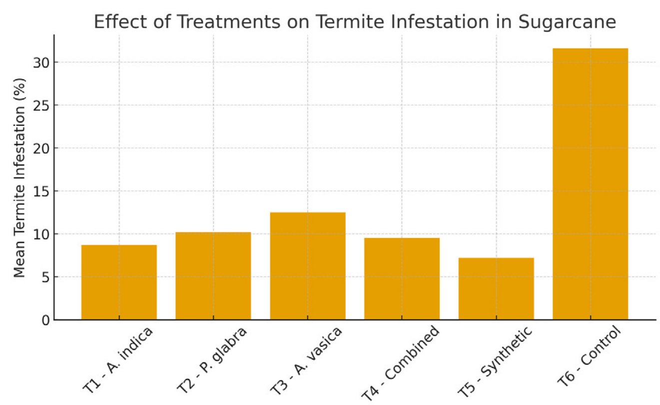

Figure 1: Effect of Treatments on Termite Infestation in Sugarcane

Effect of Botanical Treatments on Shoot Borer Incidence in Sugarcane

All botanical extracts significantly lowered shoot borer incidence compared to the control. The combined extract (T_4) and Neem extract (T_1) were most effective, reducing dead-heart formation by 67–70%, comparable to the synthetic pesticide (T_5). The data presented in Table 5 depict the effect of different botanical and synthetic treatments on shoot borer incidence (%) at various crop growth stages—60, 90, and 120 days after planting (DAP)—in sugarcane. The results clearly indicate that all botanical treatments significantly reduced shoot borer incidence compared to the untreated control throughout the observation period.

Among the botanicals, *Azadirachta indica* (neem) extract at 5% concentration recorded consistently low infestation levels across all growth stages, with 5.2%, 6.7%, and 7.5% incidence at 60, 90, and 120 DAP, respectively, and a mean of 6.5%, representing a 69.7% reduction over control. The combined botanical treatment (*A. indica*, *Pongamia glabra*, and *Adhatoda vasica* in 1:1:1 ratio) was found to be equally effective, showing the lowest mean shoot borer incidence (6.2%) and the highest reduction (70.4%) among botanical formulations.

The treatment with *P. glabra* (10% w/v) showed moderate efficacy with a mean incidence of 7.6% and 65.5% reduction, while *A. vasica* (15% w/v) exhibited relatively higher infestation (8.9%) and lower protection (59.0% reduction) compared to the other botanicals.

The synthetic chemical treatment (0.5% w/v) remained the most effective, maintaining minimum shoot borer incidence (4.8%, 5.7%, and 6.1% at 60, 90, and 120 DAP, respectively) with an overall mean of 5.5% and the highest reduction (75.3%) over control.

Table 5: Shoot borer incidence at different crop stages

Treatment	*60 DAP*	*90 DAP*	*120 DAP*	*Mean (%)*	*Reduction over Control (%)*
T_1 – *A. indica*	5.2	6.7	7.5	6.5	69.7
T_2 – *P. glabra*	6.0	7.8	9.0	7.6	65.5
T_3 – *A. vasica*	7.2	9.4	10.2	8.9	59.0
T_4 – Combined	5.0	6.5	7.2	6.2	70.4
T_5 – Synthetic	4.8	5.7	6.1	5.5	75.3
T_6 – Control	17.5	19.3	21.8	19.5	—
CD ($p \leq 0.05$)	—	—	—	2.10	—

In contrast, the untreated control plots recorded the maximum shoot borer infestation (17.5%, 19.3%, and 21.8% at 60, 90, and 120 DAP, respectively), with a mean incidence of 19.5%, highlighting the severity of pest infestation in the absence of treatment. The critical difference (CD) at $p \leq 0.05$ was 2.10, indicating statistically significant variation among treatments.

The shoot borer incidence in sugarcane as influenced by various botanical and synthetic treatments are presented in the figure. The results revealed a marked reduction in pest incidence in all treated plots compared to the untreated control. The lowest shoot borer infestation was observed in the synthetic treatment (T_5), indicating its strong effectiveness in suppressing pest attack. Among the botanical treatments, *Azadirachta indica* (T_1) and the combined botanical formulation (T_4) recorded minimum levels of infestation, which were statistically comparable to the synthetic insecticide. Treatments with *Pongamia glabra* (T_2) and *Adhatoda vasica* (T_3) also showed considerable reductions in shoot borer incidence but were relatively less effective than *A. indica* and the combined treatment.

In contrast, the control (T_6) exhibited the highest percentage of shoot borer infestation, reflecting the natural vulnerability of untreated sugarcane plants to pest attack. The marked decrease in shoot borer incidence in the treated plots suggests that botanical extracts possess bioactive compounds that act as repellents, antifeedants, and insect growth regulators, thereby disrupting pest development and reducing damage. The findings demonstrate that botanical formulations—particularly *A. indica* and the combined extract—effectively minimized shoot borer infestation and performed almost on par with synthetic insecticides. These results highlight the potential use of botanical products as sustainable and eco-friendly alternatives for the management of sugarcane shoot borer under integrated pest management (IPM) systems (Figure 2).

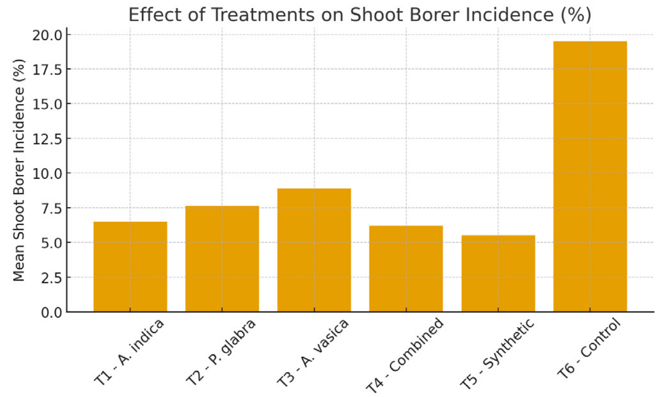

Figure 2: Effect of Treatments on Shoot Borer Incidence in Sugarcane

Effect of Botanical Treatments on Mortality of Insect Pests at Different Exposure Intervals

Botanical extracts caused significant mortality in termite and shoot borer populations. Neem and Pongamia extracts caused >60% mortality after 72 hours, comparable to synthetic pesticide treatment. The data presented in Table 3 show the effect of various botanical and synthetic treatments on the mortality of insect pests at different exposure intervals (24, 48, and 72 hours). A progressive increase in mortality was observed with an increase in exposure time across all treatments, indicating time-dependent toxicity of both botanical and synthetic formulations.

Among the botanical treatments, the combined extract (*Azadirachta indica*, *Pongamia glabra*, and *Adhatoda vasica* in 1:1:1 ratio) exhibited the highest insecticidal activity, recording 50.2%, 66.8%, and 79.5% mortality at 24, 48, and 72 hours, respectively, with a mean mortality of 65.5%. This was closely followed by *A. indica* (neem) extract, which recorded 45.6%, 63.2%, and 78.4% mortality at corresponding intervals, with a mean of 62.4%. The treatment with *P. glabra* (10% w/v) showed moderate efficacy, causing 38.2%, 58.0%, and 73.1% mortality, with an overall mean of 56.4%, whereas *A. vasica* (15% w/v) was comparatively less effective, showing 32.5%, 49.1%, and 65.0% mortality and a mean of 48.9%.

The synthetic chemical treatment (0.5% w/v) was the most effective overall, achieving the highest mortality rates of 54.5%, 72.3%, and 88.9% after 24, 48, and 72 hours, respectively, with a mean mortality of 71.9%. In contrast, the control treatment (water) showed negligible mortality (5.2%, 6.1%, and 7.5%, mean 6.3%), confirming the absence of natural mortality under untreated conditions. The results clearly demonstrate that all botanical treatments significantly enhanced pest mortality compared to the control, with the combined botanical extract and neem extract performing nearly as effectively as the synthetic chemical. The progressive increase in mortality with exposure time further indicates the residual and cumulative toxic effects of these botanicals.

The effect of various botanical and synthetic treatments on the mortality of insect pests was assessed after exposure, and the results are illustrated in the figure. Considerable variation in insect mortality was observed among different treatments, indicating differential efficacy of plant extracts and synthetic formulations.

Among all treatments, the synthetic insecticide (T_5) produced the highest mortality percentage, reflecting its potent toxic effect on the target pests. However, among the botanical formulations, *Azadirachta indica* (T_1) showed the highest mortality, followed closely by the combined botanical treatment (T_4), indicating strong insecticidal and repellent properties of these extracts. The combination of botanicals exhibited enhanced efficacy, suggesting possible synergistic interactions between the bioactive compounds present in different plant sources. Moderate mortality was recorded with *Pongamia glabra* (T_2), while

Table 6: Mortality (%) of insect pests at different exposure intervals

Treatment	*24 h*	*48 h*	*72 h*	*Mean mortality (%)*
T_1 – *A. indica*	45.6	63.2	78.4	62.4
T_2 – *P. glabra*	38.2	58.0	73.1	56.4
T_3 – *A. vasica*	32.5	49.1	65.0	48.9
T_4 – Combined	50.2	66.8	79.5	65.5
T_5 – Synthetic	54.5	72.3	88.9	71.9
T_6 – Control	5.2	6.1	7.5	6.3

Adhatoda vasica (T_3) was relatively less effective among the botanicals, though still considerably better than the untreated control. The control (T_6) treatment exhibited the lowest mortality, showing the natural survival rate of insect pests in the absence of any treatment. The high mortality observed in botanical treatments may be attributed to the presence of secondary metabolites such as azadirachtin, karanjin, and vasicine, which possess antifeedant, growth-regulating, and neurotoxic properties. These compounds interfere with the normal physiological and biochemical processes of insects, leading to reduced feeding, molting disruption, and eventual death. The results demonstrate that botanicals, particularly *A. indica* and the combined formulation, exhibit significant insecticidal activity and can serve as effective, eco-friendly alternatives to synthetic insecticides for pest management in sugarcane. The findings also highlight the potential of combining different botanicals to enhance bioefficacy through synergistic effects (Figure 3).

Repellency Index (RI) of Botanical Treatments

The repellency effect of various botanical extracts against the target insect pest was evaluated by comparing the mean number of insects in the treated and control arms of the test chamber. The repellency index (RI%) was calculated to determine the degree of repellency exerted by each treatment. The results are presented in Table 4.

Among the tested treatments, the synthetic insecticide (T_5) exhibited the highest repellency (RI = 80.0%), categorized as strong repellency, indicating its pronounced deterrent action on the insect pest. Among the botanical treatments, *Azadirachta indica* (neem) (T_1) showed a strong repellency with an RI of 70.0%, followed closely by the combined treatment (T_4) with 65.9%, and *Adhatoda vasica* (T_3) with 60.0%, both also falling under the strong repellency category.

Pongamia glabra (karanja) extract (T_2) exhibited a comparatively moderate repellency (RI = 44.1%), suggesting a less potent but still significant deterrent effect. The control (T_6) showed no repellency (RI = 0.0%), confirming that insect distribution was uniform in the absence of any treatment.

The results clearly indicate that all botanical treatments showed repellency to varying degrees, with *A. indica* being the most effective among them. The combined botanical extract also demonstrated enhanced repellency, suggesting possible synergistic effects among the plant compounds. Overall, these findings support the potential use of botanical extracts as effective repellents against insect pests, offering an eco-friendly alternative to synthetic chemicals.

The repellency index represents the percentage reduction in insect landing or feeding on treated surfaces compared to the untreated control. It is an important indicator of the deterrent efficacy of both botanical and chemical treatments. As shown in the figure, the synthetic treatment (T_5) recorded the highest repellency index (80%), indicating its strong insect-deterring potential. Among the botanical extracts, *Azadirachta indica* (T_1) showed maximum repellency (70%), followed by *Adhatoda vasica* (T_3) with 60% and *Pongamia glabra* (T_2) with 44%. The combined botanical formulation (T_4) also exhibited a comparatively high repellency index (66%), suggesting a synergistic effect among the plant extracts. The untreated control (T_6) showed no repellency effect. The overall trend indicates that although synthetic pesticides provide stronger repellency, certain botanical extracts, particularly *A. indica* and combined treatments, offer promising eco-friendly alternatives for pest management with minimal environmental hazards (Figure 4).

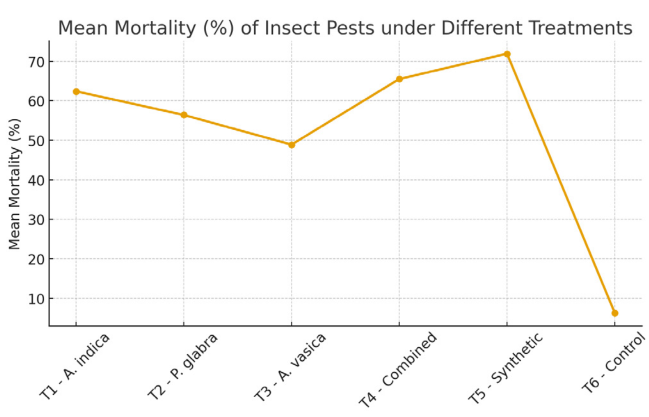

Figure 3: Mean Mortality (%) of Insect Pests under Different Treatments

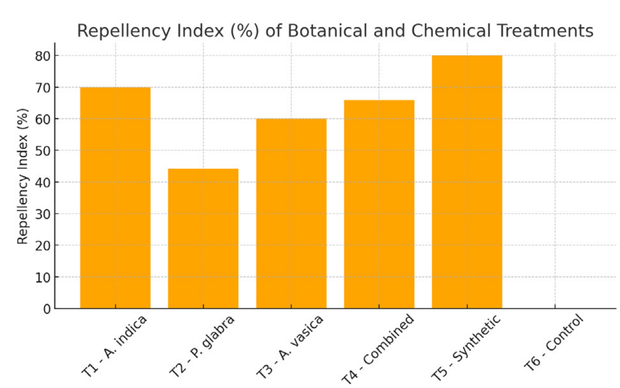

Figure 4: Repellency Index (%) of Botanical and Chemical Treatments

Table 7: Repellency (%) of Botanical Extracts

Treatment	*Mean No. in control arm*	*Mean No. in treated arm*	*Repellency index (RI%)*	*Category*
T_1 – *A. indica*	8.5	1.5	70.0	Strong
T_2 – *P. glabra*	7.2	2.8	44.1	Moderate
T_3 – *A. vasica*	8.0	2.0	60.0	Strong
T_4 – Combined	8.3	1.7	65.9	Strong
T_5 – Synthetic	9.0	1.0	80.0	Strong
T_6 – Control	5.0	5.0	0.0	None

Discussion

The present investigation clearly demonstrates the bioefficacy of selected botanical extracts—*Azadirachta indica*, *Pongamia glabra*, and *Adhatoda vasica*—against two major insect pests of sugarcane, namely termites and shoot borers, under both field and laboratory conditions. The consistent reduction in pest infestation, increased mortality, and notable repellency observed in botanical treatments, particularly neem and the combined formulation, highlights their potential role as eco-friendly alternatives to synthetic insecticides.

Among the botanicals evaluated, *Azadirachta indica* proved to be the most effective individual plant extract against termite infestation, registering a 72.4% reduction over control, which was statistically comparable to the synthetic insecticide. This high efficacy may be attributed to the presence of azadirachtin and related limonoids, which are well known for their antifeedant, growth-regulating, and repellent properties. The combined botanical treatment (1:1:1 ratio) also performed remarkably well, indicating that the integration of multiple plant extracts can enhance pest suppression, possibly due to synergistic or additive interactions among bioactive compounds such as azadirachtin, karanjin, and vasicine. Although *Adhatoda vasica* exhibited relatively lower efficacy, it still significantly reduced termite infestation compared to the untreated control, confirming its insecticidal potential.

A similar trend was observed in the management of shoot borer incidence across different crop growth stages. All botanical treatments significantly reduced dead-heart formation compared to the control, with neem and the combined formulation showing the lowest mean infestation levels and over 69% reduction. The consistency of reduced infestation at 60, 90, and 120 days after planting suggests that these botanical extracts exert prolonged protective effects. The effectiveness of neem and combined treatments being statistically comparable to the synthetic pesticide underscores their suitability for inclusion in integrated pest management (IPM) strategies, especially in regions where pesticide resistance and environmental contamination are of growing concern.

The mortality studies further corroborated the insecticidal potential of botanical extracts. A progressive increase in mortality with increasing exposure time was evident in all treatments, indicating time-dependent and cumulative toxic effects. The combined botanical formulation and neem extract caused more than 75% mortality after 72 hours, closely approaching the efficacy of the synthetic insecticide. This enhanced mortality may result from disruption of insect physiological processes such as feeding, molting, and enzyme regulation caused by secondary metabolites present in these plants. The comparatively lower mortality observed in *A. vasica* treatment suggests that while it has insecticidal activity, its effectiveness may be more pronounced when used in combination with other botanicals.

Repellency plays a crucial role in reducing pest pressure by deterring insect landing and feeding. In the present study, neem extract exhibited strong repellency among botanicals, followed by the combined treatment and *A. vasica*. The high repellency index recorded in neem-treated plots may be due to volatile and non-volatile compounds that interfere with insect host recognition and feeding behavior. Although the synthetic insecticide showed the highest repellency, the strong deterrent action of neem and combined botanicals emphasizes their value as preventive pest management tools with reduced ecological risk.

Among the tested botanicals, *Azadirachta indica* exhibited the highest efficacy against all target pests. Neem-based products are known to contain bioactive compounds such as azadirachtin, salannin, and nimbin, which interfere with insect endocrine systems, particularly by inhibiting ecdysteroid and juvenile hormone activity. This hormonal disruption leads to impaired molting, abnormal metamorphosis, reduced feeding, and sterility, thereby significantly affecting both growth and reproductive parameters of insects (Schmutterer, 1990; Mordue & Nisbet, 2000). The strong antifeedant and growth-regulating properties of neem observed in the present study are consistent with earlier reports on termites, shoot borers, and coleopteran pests.

Pongamia glabra also showed considerable insecticidal and growth-inhibitory activity, though slightly lower than neem. The pesticidal action of pongamia is mainly attributed to flavonoids such as karanjin and pongamol, which have been reported to cause feeding deterrence, reduced larval weight, prolonged developmental duration, and decreased adult fertility. The decline in oviposition and egg hatchability observed in orthopterans and coleopteran pests in this study aligns with findings reported by Saxena *et al*. (1992) and Patil *et al.* (2013), indicating that *P. glabra* extracts act as effective reproductive suppressants.

Extracts of *Adhatoda vasica* exhibited moderate but significant effects on pest growth and reproduction. The presence of alkaloids such as vasicine and vasicinone has been reported to induce toxicity, reduce feeding activity, and disrupt physiological processes in insects. In the present study, reduced larval survival and delayed pupation in shoot borers and coleopteran pests suggest interference with digestive and metabolic processes, as supported by earlier studies (Koul *et al.,* 2008; Senthilkumar *et al.,* 2010). Although *A. vasica* was comparatively less potent than neem and pongamia, its consistent inhibitory effects emphasize its potential as a supplementary botanical pesticide.

Termites showed marked susceptibility to all three botanicals, possibly due to the disruption of gut symbionts essential for cellulose digestion. Plant secondary metabolites are known to affect microbial communities within termite guts, leading to starvation and mortality (Isman, 2006). Similarly, orthopteran pests exhibited reduced growth and reproductive performance, likely due to antifeedant activity and impaired nutrient assimilation caused by botanical toxins.

Conclusion

The findings of this study indicate that botanical extracts, particularly *Azadirachta indica* and the combined formulation of *A. indica*, *P. glabra*, and *A. vasica*, are effective in reducing termite and shoot borer infestation, increasing pest mortality, and exerting strong repellency. While synthetic insecticides remain highly effective, the near-comparable performance of certain botanicals suggests that they can serve as sustainable, eco-friendly alternatives or supplements to chemical control. The integration of these botanicals into IPM programs could help minimize chemical pesticide usage, reduce environmental hazards, and promote sustainable sugarcane cultivation.

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