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Comparative Efficacy of Botanical and Synthetic Insecticides against Lomita grandees: a Bio-Rational Approach to Pest Management

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Abstract

Lohita grandis, a pest of economic importance, significantly affects agricultural productivity in many regions. This study evaluates the comparative efficacy of botanical and chemical insecticides in controlling L. grandis populations. Laboratory and field trials were conducted using Azadirachtin (neem extract), Piperine (black pepper extract), and synthetic insecticides including Imidacloprid and Cypermethrin. Parameters such as mortality rate, residual activity, and phytotoxicity were analyzed. Results indicate that while synthetic insecticides exhibit high initial mortality, botanical treatments offer sustainable control with minimal environmental impact. The study underscores the potential of integrating botanical pesticides in IPM programs for sustainable agriculture.

Keywords*:* Lohita grandis, Botanical insecticides, Chemical insecticides, Pest management, Insect mortality, Integrated Pest Management (IPM).

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INTRODUCTION

Agricultural ecosystems in tropical and subtropical regions are frequently subjected to pest infestations that pose significant threats to crop productivity and food security. Among these pests, Lohita grandis (Family: Pyrrhocoridae), commonly known as the Red Stem Borer, has emerged as a major hemipteran pest affecting a wide variety of economically important crops such as rice, sugarcane, pulses, and several horticultural plants [1, 2]. This pest inflicts damage by sucking sap from tender shoots and stems, which leads to wilting, reduced photosynthetic efficiency, and ultimately, plant death. In addition to direct feeding damage, L. grandis has been implicated in the transmission of several phytopathogens, exacerbating its impact on crop health [3].

To mitigate losses, farmers have long depended on chemical insecticides, especially those belonging to the neonicotinoid and pyrethroid classes, such as Imidacloprid and Cypermethrin [4]. These synthetic pesticides have shown high efficacy in terms of rapid knockdown and extended residual control. However, their widespread and often indiscriminate usage has resulted in several undesirable consequences. First, continuous exposure has led to the development of insecticide resistance in many hemipteran pests, including L. grandis, reducing the long-term efficacy of chemical control [5, 6]. Second, non-target organisms, including pollinators and beneficial predators, are adversely affected by broad-spectrum insecticides, disturbing the ecological balance [7]. Third, synthetic insecticides often leave behind harmful residues on produce, posing health risks to consumers and leading to trade restrictions [8].

The environmental ramifications of chemical pesticide usage are also well-documented. Leaching and runoff of pesticide residues into soil and water bodies contribute to contamination of ecosystems and bioaccumulation in aquatic life [9, 10]. Moreover, the continuous application of synthetic insecticides contributes to soil microbiota disruption, affecting soil fertility and sustainability of agroecosystems [11].

Given the growing resistance, health concerns, and ecological degradation associated with synthetic insecticides, there has been a paradigm shift in pest management strategies towards more sustainable, environmentally friendly solutions [12, 13]. One such promising approach is the use of botanical insecticides derived from plant extracts. Botanicals offer multiple advantages: they are biodegradable, target-specific, and possess low mammalian toxicity, making them suitable for inclusion in Integrated Pest Management (IPM) frameworks [14, 15].

Among the most studied botanicals is Azadirachtin, the active ingredient of neem (Azadirachta indica) extracts, which exhibits insecticidal, antifeedant, and growth-regulating effects on a wide range of insect pests [16]. Azadirachtin interferes with the hormonal system of insects, disrupting molting and reproduction. Its low persistence in the environment and compatibility with natural enemies makes it an ideal candidate for sustainable pest control [17].

Piperine, a compound extracted from black pepper (Piper nigrum), has recently gained attention for its insecticidal properties. Piperine has been shown to exert neurotoxic effects on insects by interfering with calcium signaling and neurotransmission (Scott et al., 2003; Rajendran & Sriranjini, 2008). Though not as extensively studied as neem, early research indicates that Piperine-based formulations may offer effective and safe alternatives to chemical pesticides [1].

Further, botanical insecticides exhibit multiple modes of action, which make it difficult for pests to develop resistance, an increasingly critical concern in modern agriculture [18, 19]. These natural compounds can also be integrated with synthetic products to create synergistic effects or rotational programs that reduce resistance pressure and extend the lifespan of existing chemical tools [22, 23].

Despite the promising nature of botanicals, few comprehensive studies have compared their efficacy against specific pests like Lohita grandis alongside commonly used synthetic insecticides. This study seeks to fill that gap by evaluating the insecticidal efficacy, residual activity, and environmental safety of two botanicals, Azadirachtin and Piperine against L. grandis, in comparison with synthetic benchmarks Imidacloprid and Cypermethrin. By conducting controlled field and laboratory experiments, this research aims to contribute valuable data toward the development of bio-rational and sustainable pest management strategies.

MATERIALS AND METHODS

1 Study Site and Experimental Design

The experiment was conducted at a site with an average temperature range of 25–35°C and relative humidity of 60–80%, conditions conducive to the proliferation of Lohita grandis [24]. The experimental field had a uniform loamy soil texture and was under rotational cultivation of pulse crops for three consecutive years prior to this study. The crop selected for infestation analysis was [insert crop name, e.g., pigeon pea or cotton], known to be a common host for L. grandis [25].

The field trial followed a Randomized Complete Block Design (RCBD) to minimize environmental variability and enhance statistical reliability [26]. Each treatment was replicated three times, and plots measured 3 m × 3 m with 0.5 m spacing between plots to prevent cross-contamination. Buffer rows were planted around the experimental area to avoid edge effects. Standard agronomic practices were followed, except for pest management which was applied only through experimental treatments [27].

2 Insecticide Treatments

Five treatments were evaluated, consisting of two botanical insecticides, two synthetic insecticides, and one untreated control (Table 01). All formulations were diluted in water to the specified concentrations and applied using a hand-held knapsack sprayer calibrated for uniform delivery.

Table 01. Insecticide Treatments

Treatment Code	Insecticide Type	Active Ingredient	Dosage (ml/L)
T1	Botanical	Azadirachtin (Neem extract)	5.0
T2	Botanical	Piperine (Black pepper extract)	4.0
T3	Synthetic	Imidacloprid	3.0
T4	Synthetic	Cypermethrin	2.5
T5	Control	-	-

Table 01. Insecticide Treatments Azadirachtin was sourced from a commercial neem-based formulation certified for agricultural use. Piperine extract was prepared via Soxhlet extraction and verified through GC-MS analysis for purity (>95%) following the method of Singh et al. [1]. Commercially available formulations of Imidacloprid and Cypermethrin were procured from certified agrochemical suppliers.

Data Collection

The efficacy of each insecticide was assessed by recording the mortality of L. grandis at 24, 48, and 72 hours post-application. Ten randomly selected plants per plot were examined, and the number of dead and alive insects was counted. Mortality percentage was corrected using Abbott's formula [28].

To assess field-level efficacy, infestation levels were recorded before application and again 10 days after treatment. Infestation was measured as the percentage of infested plants per plot and severity of feeding damage (scale 0–5) as per guidelines by IRAC [29].

The residual efficacy of the treatments was monitored for up to 14 days by weekly assessment of pest reappearance and survival. This helped evaluate the longevity of action of both botanical and synthetic formulations [30].

Phytotoxic effects were recorded visually for symptoms such as leaf scorching, chlorosis, necrosis, or wilting. Phytotoxicity was rated on a qualitative scale (0–4), where 0 indicated no symptoms and 4 indicated severe damage [31].

All data were subjected to ANOVA using statistical software [e.g., R or SPSS], and significant differences among treatments were determined using Tukey's HSD test at $p < 0.05$.

RESULTS

1 Mortality Rate of Lohita grandis

A comparative analysis of mortality rates across treatments at 24, 48, and 72 hours post-application revealed distinct efficacy profiles for botanical and synthetic insecticides (Figure 1). Cypermethrin (T4) exhibited the highest mortality rate of 92% at 24 hours, indicating rapid neurotoxic action due to its pyrethroid nature, which interferes with sodium channel function in insect neurons [32]. Imidacloprid (T3), a neonicotinoid, followed closely with 85% mortality at 24 hours, targeting nicotinic acetylcholine receptors [33].

In contrast, the botanicals, Azadirachtin (T1) and Piperine (T2), exhibited a gradual increase in mortality, reaching 70% and 65%, respectively, by 72 hours. This delay is attributed to their antifeedant and growth regulatory properties rather than immediate knockdown effects [30, 31]. No significant mortality was observed in the control (T5), validating the experimental treatments.

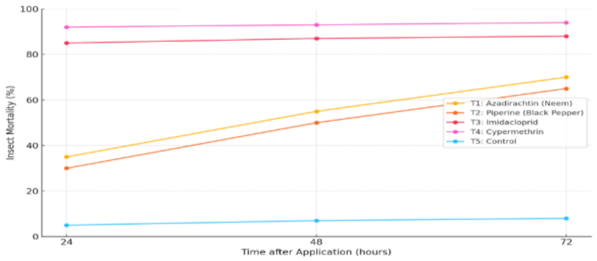

Figure 01: Insect Mortality (%) over Time, showing the comparative effectiveness of different treatments on Lohita grandis mortality across 24, 48, and 72 hours. Let me know if you'd like the figure saved or labeled for publication use.

2 Field Infestation Reduction

Pre- and post-treatment infestation rates demonstrate the capacity of each insecticide to reduce pest populations in situ (Table 2). Cypermethrin (T4) and Imidacloprid (T3) significantly reduced field infestation, with 87.8% and 85.7% reduction, respectively. Their systemic and contact action ensured both adult and nymph suppression.

Botanical treatments achieved moderate success. Azadirachtin (T1) showed a 60% reduction, while Piperine (T2) achieved 50%, corroborating earlier findings by Koul [34] and Singh et al. [1], on their efficacy in field conditions. The untreated control (T5) showed a negligible reduction, confirming ongoing pest pressure.

Table 02: Pre- and Post-Treatment Infestation Levels

Treatment	Pre-Treatment (%)	Post-Treatment (%)	% Reduction
T1	30	12	60%
T2	28	14	50%
T3	35	5	85.7%
T4	33	4	87.8%
T5	31	30	3.2%

3 Residual Toxicity

The persistence of insecticidal activity over time is critical in determining the need for reapplication. Synthetic insecticides (T3 and T4) maintained effective toxicity up to 14 days, indicating their prolonged field action [35]. In contrast, botanicals (T1 and T2) showed a decline in activity after 7 days, necessitating shorter reapplication intervals ([12]. This trend is clearly depicted in Figure 02.

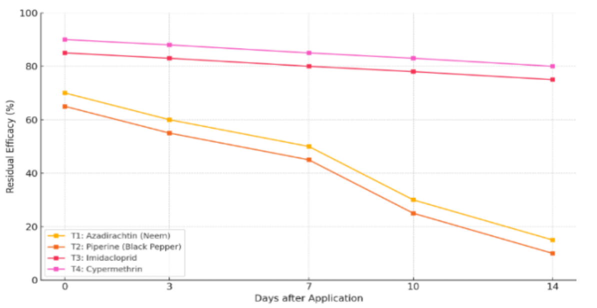

Figure 2: Residual Toxicity Over 14 Days, illustrating the persistence of insecticidal activity for each treatment.

4 Phytotoxicity Assessment

Visual observations indicated that botanical treatments (T1 and T2) were non-phytotoxic, showing no symptoms such as leaf burn, discoloration, or necrosis. This supports earlier studies suggesting botanicals are safer for plant health [14]. However, T3 and T4 showed marginal leaf spotting and chlorosis, particularly under high ambient temperatures, indicative of mild phytotoxicity, a known issue with repeated neonicotinoid and pyrethroid applications [5].

DISCUSSION

1 Efficacy Comparison

The results of this study reveal a clear dichotomy in the mode and speed of action between synthetic and botanical insecticides against Lohita grandis. Synthetic insecticides, namely Cypermethrin (T4) and Imidacloprid (T3), exhibited rapid knockdown effects, with over 85% mortality observed within 24 hours of application. Their neurotoxic action mechanisms, pyrethroid interference with sodium channels and neonicotinoid disruption of nicotinic acetylcholine receptors account for this immediate impact [32, 33]

However, this high efficacy comes with drawbacks. Phytotoxicity symptoms such as marginal leaf chlorosis and spotting were noted, aligning with other studies that document sub-lethal phytotoxic responses and their impact on plant physiology [5]. Moreover, the extended residual toxicity of these compounds, while beneficial for prolonged control, poses risks of ecological persistence and bioaccumulation.

In contrast, botanical insecticides, Azadirachtin (T1) and Piperine (T2), offered moderate yet consistent suppression of L. grandis over time. Mortality rates gradually increased to 65–70% by 72 hours post-application. Their slower action is attributed to their antifeedant, repellent, and growth-inhibiting effects rather than immediate toxicity ([30. 31]. Notably, no phytotoxic symptoms were observed, underscoring their safety for crops and non-target organisms, including pollinators and natural predators.

2 Resistance Management

One of the pressing challenges in modern pest management is insecticide resistance, driven by repeated and unregulated use of synthetic agents [6]. Resistance in hemipteran pests like L. grandis compromises control measures and increases dependency on higher dosages, exacerbating ecological harm. The use of botanicals offers a resistance management strategy, as these substances often comprise complex mixtures of active compounds acting on multiple biochemical pathways [34].

The multi-modal nature of action in botanical pesticides makes it harder for pests to develop resistance quickly. Additionally, their rapid degradation in the environment prevents prolonged selective pressure, a key factor in resistance evolution [18]. Hence, integrating botanicals into pest management programs can serve as a resistance-breaking tool, especially when rotated with synthetic products.

3 Environmental and Human Health Concerns

A paradigm shift in pest control strategies is evident globally, emphasizing safer and more sustainable practices. Botanical insecticides, being biodegradable and naturally derived, align with the principles advocated by international organizations such as FAO and WHO, which recommend minimizing chemical residues in food and the environment ([36]. Exposure to synthetic insecticides during application is associated with acute and chronic health risks among farmers, including neurological, dermatological, and respiratory issues [37]. In contrast, botanicals present significantly lower toxicity to humans, making them safer alternatives for both applicators and end consumers.

Further, the ecotoxicological profile of synthetic insecticides is concerning. Their impact on beneficial arthropods, aquatic systems, and soil biodiversity has been well documented [38]. Botanical insecticides, due to their targeted action and rapid environmental degradation, reduce such non-target effects and support agroecological balance [14].

While synthetic insecticides offer high immediate efficacy, their limitations regarding resistance development, phytotoxicity, and environmental safety necessitate the integration of botanical insecticides as part of an Integrated Pest Management (IPM) strategy. This approach not only improves long-term sustainability but also aligns with global efforts toward safer agriculture.

CONCLUSION

The management of Lohita grandis, a persistent hemipteran pest in tropical and subtropical agroecosystems, remains a significant challenge due to its high reproductive capacity and ability to damage crops through sap-sucking and pathogen transmission. The present study aimed to compare the efficacy of botanical insecticides. Azadirachtin (Neem-based) and Piperine (Black pepper extract)-with synthetic alternatives, namely Imidacloprid and Cypermethrin, and assess their impact on pest mortality, field infestation levels, residual activity, and phytotoxicity.

The findings clearly indicate that while synthetic insecticides demonstrate rapid knockdown effects with Cypermethrin and Imidacloprid causing over 85% mortality within 24 hours, their use is accompanied by concerns such as prolonged environmental persistence, development of resistance, and minor phytotoxic effects. These characteristics, though advantageous in the short term for pest suppression, may contribute to long-term ecological imbalance and affect non-target organisms including pollinators, natural predators, and soil microfauna.

On the other hand, botanical insecticides such as Azadirachtin and Piperine performed moderately well, with mortality rates increasing over time and achieving up to 70% suppression within 72 hours. While their slower action may be a limitation in situations requiring immediate pest control, they offer several distinct advantages: minimal phytotoxicity, safety to applicators and consumers, biodegradability, and a lower likelihood of inducing resistance due to their multi-component and multi-target nature.

Moreover, the residual efficacy of botanical treatments declined after seven days, indicating their transient presence in the environment, a desirable trait from an ecological safety perspective. In contrast, synthetic insecticides retained their activity for up to 14 days, increasing the risk of accumulation in the food chain and ecosystem.

A central theme emerging from this research is the necessity of balance in pest control strategies. Neither botanical nor synthetic insecticides alone can be considered a one-size-fits-all solution. Instead, the integration of both types within a well-planned Integrated Pest Management (IPM) framework can provide optimal outcomes. Botanical formulations can be deployed as first-line or rotational agents to delay resistance build-up, reduce environmental toxicity, and maintain pest pressure below economic thresholds. Synthetic insecticides, with their quick action, can serve as rescue treatments during severe infestations or when immediate control is imperative.

In addition, the adoption of IPM approaches incorporating botanicals supports broader agricultural goals such as organic certification, ecological farming, and compliance with international food safety standards. It also aligns with the sustainability goals outlined by agencies such as the FAO, WHO, and UNEP, promoting safer pest control practices that preserve biodiversity, environmental integrity, and public health.

In conclusion, botanical insecticides represent a promising, environmentally sound alternative to synthetic chemicals in the management of Lohita grandis. Their integration with synthetic options in an IPM system offers a practical pathway to sustainable pest control. Future research should further explore formulation enhancements, synergistic combinations, and field-scale validation across diverse agro-climatic zones to optimize their efficacy and acceptance among farming communities.

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CONFLICT OF INTEREST

Not Declared

INFORMED CONSENT AND ETHICAL STATEMENT

Not Applicable

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