

BOTANICAL PESTICIDE APPLICATIONS FOR SUSTAINABLE PEST MANAGEMENT IN SHALLOT-BASED CROPPING SYSTEMS

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ABSTRACT

Reducing dependency on synthetic pesticides is a central challenge in advancing sustainable horticultural production systems. This study evaluated the effectiveness of *Lantana camara* leaf extract as a botanical pesticide for managing *Spodoptera exigua* in shallot-based cropping systems under field conditions. A randomized complete block design was applied with four extract concentrations, and observations included pest infestation intensity, leaf damage progression, plant vigor, yield performance, and phytotoxicity. The results showed a clear dose-dependent reduction in infestation intensity, with the highest concentration achieving the greatest suppression, while the moderate concentration provided the optimal balance between pest control and crop performance. Treated plots exhibited delayed larval development, improved plant vigor, and higher yield compared to the untreated control. Mild phytotoxic effects were observed only at the highest concentration, indicating the importance of dosage optimization. These findings demonstrate that plant-derived extracts can effectively reduce pest pressure while maintaining crop productivity. The study highlights the potential of botanical pesticide applications as a component of sustainable pest management strategies within shallot-based cropping systems, supporting reduced chemical reliance and enhanced agroecosystem resilience.

Keywords:

ekstrak tumbuhan, pengelolaan terpadu, pengendalian hama, pertanian berkelanjutan, pestisida nabati, sistem pertanian, stabilitas hasil panen.

ABSTRACT

Mengurangi ketergantungan pada pestisida sintesis merupakan tantangan utama dalam memajukan sistem produksi hortikultura berkelanjutan. Studi ini mengevaluasi efektivitas ekstrak daun *Lantana camara* sebagai pestisida nabati untuk mengendalikan *Spodoptera exigua* pada sistem budidaya bawang merah di bawah kondisi lapangan. Desain blok acak lengkap diterapkan dengan empat konsentrasi ekstrak, dan pengamatan meliputi intensitas serangan hama, perkembangan kerusakan daun, kekuatan tanaman, kinerja hasil panen, dan fitotoksitas. Hasil menunjukkan pengurangan intensitas serangan yang jelas bergantung pada dosis, dengan konsentrasi tertinggi mencapai penekanan terbesar, sementara konsentrasi sedang memberikan keseimbangan optimal antara pengendalian hama dan kinerja tanaman. Petak yang diberi perlakuan menunjukkan perkembangan larva yang tertunda, peningkatan kekuatan tanaman, dan hasil panen yang lebih tinggi dibandingkan dengan kontrol tanpa perlakuan. Efek fitotoksik ringan hanya diamati pada konsentrasi tertinggi, menunjukkan pentingnya optimasi dosis. Temuan ini menunjukkan bahwa ekstrak yang berasal dari tumbuhan dapat secara efektif mengurangi tekanan hama sambil mempertahankan produktivitas tanaman. Studi ini menyoroti potensi aplikasi pestisida nabati sebagai komponen strategi pengelolaan hama berkelanjutan dalam sistem pertanian berbasis bawang merah, mendukung pengurangan ketergantungan bahan kimia dan peningkatan ketahanan agroekosistem.

INTRODUCTION

The transition toward sustainable agricultural systems has intensified global attention on reducing synthetic pesticide dependency while maintaining crop productivity. Conventional chemical-based pest control, although effective in the short term, has generated ecological concerns including pest resistance, environmental contamination, and disruption of agroecosystem balance (Abrol & Shankar, 2014; Priya et al., 2023). These challenges have encouraged the integration of plant-derived bioactive compounds into sustainable pest management strategies, particularly within cropping systems that rely heavily on repeated pesticide applications.

Botanical pesticides, derived from plant secondary metabolites such as terpenoids, alkaloids, phenolics, and other bioactive compounds, have been widely recognized for their insecticidal, repellent, and growth-disrupting properties (Aioub et al., 2024; Saxena et al., 2014). Compared with synthetic pesticides, plant-based extracts are generally biodegradable, less persistent in the environment, and compatible with integrated pest management (IPM) frameworks (Chowdhury et al., 2024; Dar et al., 2022; Zhou et al., 2024). However, their effectiveness often varies depending on plant species, concentration, pest biology, and cropping system context. Consequently, localized empirical evaluations remain essential to assess their practical relevance within specific production systems.

Shallot (*Allium ascalonicum* L.) represents a high-value horticultural commodity cultivated extensively in tropical regions (Harahap et al., 2022; Rahim et al., 2022; Rahim et al., 2019). Beyond its culinary importance, shallot contributes significantly to farmer income and regional food supply chains (Nurhapsa & Suherman, 2023). Optimal production depends on appropriate cultivation practices, including pest and disease management (Nurhapsa et al., 2017; 2023). In tropical agroecosystems, one of the most destructive pests affecting shallots is the beet armyworm, *Spodoptera exigua* (Hübner), which can cause substantial yield losses by damaging leaf tissues during vegetative growth (Aldini et al., 2020; Aminah et al., 2024; Supartha et al., 2022). Severe infestations reduce photosynthetic capacity, impair bulb formation, and ultimately lower marketable yield (Khulbe & Batra, 2024).

Farmers commonly rely on synthetic insecticides to control *S. exigua* populations (Hafeez et al., 2022; Nurhapsa et al., 2023). While these practices provide immediate suppression, repeated use increases production costs and may contribute to ecological imbalances within shallot-based cropping systems (Ginting et al., 2024). Within the broader perspective of sustainable pest management, the exploration of locally available botanical resources offers a promising complementary approach. *Lantana camara* L., commonly known as tembelean, is a shrub species known to contain secondary metabolites associated with bioactive and repellent properties (Hoang et al., 2024; Kapitan et al., 2023; Liambilla et al., 2020; Mustapa et al., 2023). Although its chemical constituents suggest insecticidal potential, systematic field-based evaluation of its extract within shallot cropping systems remains limited.

Understanding how botanical extracts influence pest intensity and crop performance under field conditions is critical to situating plant-derived pesticides within sustainable production strategies. Evaluating not only pest suppression but also crop response allows a more comprehensive assessment of their functional role within cropping systems. Therefore, this study

aims to examine the effectiveness of different concentrations of *Lantana camara* leaf extract in reducing the intensity of *S. exigua* infestation and to assess its implications for shallot yield under field conditions. By situating botanical pesticide application within a cropping system framework, this research contributes empirical evidence relevant to sustainable pest management in shallot-based production systems.

RESEARCH METHODS

Experimental Site and Cropping System

The field experiment was conducted in a shallot-producing area under open-field conditions during one planting season. The experimental site represents a typical shallot-based cropping system characterized by intensive management practices and vulnerability to insect pest infestations, particularly leaf-feeding larvae. Standard agronomic practices for shallot cultivation, including land preparation, planting density, fertilization, irrigation, and weed management, were applied uniformly across all experimental plots to minimize confounding effects.

Experimental Design and Treatments

The experiment employed a Randomized Complete Block Design (RCBD) to account for field heterogeneity. Treatments consisted of different concentrations of *Lantana camara* leaf extract applied as a botanical pesticide. Each treatment was replicated across multiple blocks to ensure statistical reliability.

The treatments included: control or no botanical pesticide application (T0), low concentration of *L. camara* leaf extract (T1), medium concentration of *L. camara* leaf extract (T2), and high concentration of *L. camara* leaf extract (T3). Treatments were randomly assigned within each block. Plot size and plant spacing followed standard recommendations for shallot cultivation, ensuring adequate representation of plant–pest interactions at the plot level.

Preparation of Botanical Pesticide Extract

Fresh leaves of *Lantana camara* were collected from healthy plants and thoroughly washed to remove surface contaminants. The leaves were air-dried under shade conditions to preserve bioactive compounds and then ground into a coarse powder. The extraction process followed a cold maceration technique, which is widely used for preserving heat-sensitive secondary metabolites.

Leaf powder was soaked in distilled water at predetermined ratios corresponding to the treatment concentrations. The mixture was allowed to macerate for 24 hours at ambient temperature with periodic stirring to enhance compound dissolution. After maceration, the extract was filtered using fine muslin cloth to remove solid residues. The filtrate was used immediately to minimize degradation of bioactive compounds. No synthetic surfactants were added to avoid altering the natural efficacy of the extract. This extraction approach ensures reproducibility while maintaining ecological relevance for smallholder-scale application.

Application of Botanical Pesticide

The botanical pesticide solution was applied using a hand-operated sprayer, ensuring uniform coverage of the plant canopy. Applications were conducted at regular intervals during the

vegetative growth stage when pest infestation risk was highest. The timing and frequency of application were standardized across treatments to allow meaningful comparison of treatment effects.

Observed Variables

To capture the systemic response of the cropping system, observations were conducted on multiple response variables:

- 1) Pest infestation intensity, measured as the percentage of damaged leaf area caused by *Spodoptera exigua*;
- 2) Plant growth response, assessed through visual vigor scoring and leaf condition;
- 3) Yield components, including fresh bulb weight per plot and estimated yield per hectare;
- 4) Phytotoxicity symptoms, observed to assess potential negative effects of the extract on plant health.

By integrating pest, plant, and yield variables, the study evaluates botanical pesticide performance beyond single-response indicators.

Data Analysis

Quantitative data were subjected to analysis of variance (ANOVA) appropriate for a randomized complete block design. When significant treatment effects were detected, mean separation was performed using a post-hoc test at a 5% significance level. Before analysis, data were examined for normality and homogeneity of variance to ensure compliance with ANOVA assumptions.

Methodological Rationale

The methodological approach integrates botanical pesticide application within a shallot-based cropping system framework. By combining field experimentation, system-relevant response variables, and statistically rigorous analysis, the study provides evidence that is both agronomically meaningful and aligned with sustainable pest management principles.

RESULTS AND DISCUSSION

Effects of Botanical Pesticide on Pest Infestation Dynamics

The intensity of *Spodoptera exigua* infestation was significantly influenced by the application of *Lantana camara* leaf extract, as shown in Table 1. All botanical pesticide treatments resulted in substantially lower infestation intensity compared to the untreated control, with the highest concentration (30%) achieving the greatest reduction (63.79%). This trend indicates a clear dose-dependent response, suggesting that increased extract concentration enhances pest suppression effectiveness.

The temporal progression of leaf damage further supports this pattern (Table 2). Control plots experienced rapid pest population development, leading to severe defoliation and plant mortality in the later growth stages. In contrast, treated plots—particularly those receiving medium and high concentrations—exhibited delayed egg hatching, reduced feeding activity, and lower cumulative damage. These results are consistent with studies reporting that botanical extracts can disrupt insect

life cycles through antifeedant, oviposition-deterrent, and growth-regulating effects (Martini et al., 2018; Susanti et al., 2015).

Table 1. Effect of *Lantana camara* leaf extract on pest infestation intensity (%)

Treatment	Extract Concentration	Infestation Intensity (%)	Reduction vs Control (%)
T0 (control)	0% (Control)	50.62 ± 2.10	–
T1 (low)	10%	27.70 ± 1.85	45.27
T2 (medium)	20%	22.07 ± 1.63	56.39
T3 (high)	30%	18.33 ± 1.41	63.79

Note: Values represent mean ± standard deviation.

Biological Mechanisms Underlying Pest Suppression

The effectiveness of *L. camara* extract can be attributed to its secondary metabolites, including terpenoids and phenolic compounds, which have been reported to interfere with insect nervous systems and digestive processes. Such compounds may reduce larval feeding efficiency and survival, leading to lower infestation levels over time. The delayed egg hatching observed in treated plots (Table 2) suggests that the extract may also exert ovicidal or oviposition-deterrent effects, as documented in previous laboratory and field studies on plant-derived insecticides (Kuppusamy et al., 2016; Pohlit et al., 2011). From a cropping system perspective, these mechanisms help maintain functional leaf area during critical vegetative stages, thereby supporting sustained plant growth and productivity.

Table 2. Weekly progression of leaf damage severity (1–8 Weeks After Planting)

Week	T0 (Control)	T1 (10%)	T2 (20%)	T3 (30%)
1	Egg deposition observed	Egg deposition	Minimal egg presence	Delayed egg presence
2	Egg hatching	Limited hatching	Low egg density	No hatching observed
3	Visible leaf perforation	Minor perforation	Slight perforation	No visible damage
4	Severe feeding damage	Moderate feeding	Mild feeding	Early minor damage
5	Leaf discoloration	Moderate damage	Mild discoloration	Minor symptoms
6	Plant tissue drying	Leaf yellowing	Mild drying	Slight yellowing
7	100% infestation (block 3)	Severe wilting	Moderate drying	Mild drying
8	Extensive plant mortality	Leaf death observed	Limited plant death	Minimal mortality

Plant Growth Response and Yield Performance

Plant vigor scores increased markedly under botanical pesticide treatments (Table 3), indicating that reduced pest pressure translated into improved plant physiological condition. The medium concentration treatment (20%) produced the highest vigor score, suggesting an optimal balance between pest suppression and plant tolerance.

Yield performance followed a similar trend (Table 4). The highest estimated yield (7.35 t/ha) was recorded under the medium concentration treatment, exceeding both the control and the highest concentration treatment. While the 30% concentration effectively reduced pest infestation, mild phytotoxic symptoms were observed (Table 5), which may have constrained yield gains. This trade-off highlights the importance of optimizing botanical pesticide dosage within cropping systems to maximize agronomic benefits while minimizing negative plant responses.

Comparable findings have been reported in international studies, where moderate concentrations of botanical extracts provided effective pest control without compromising crop performance, whereas excessive concentrations increased the risk of phytotoxicity (Abdurrahman et al., 2024; Akram et al., 2024).

Table 3. Plant vigor score (Scale 1–5)

Treatment	Vigor Score	Interpretation
T0 (control)	2.1 ± 0.3	Low vigor
T1 (low)	3.2 ± 0.4	Moderate vigor
T2 (medium)	3.8 ± 0.3	Good vigor
T3 (high)	3.5 ± 0.4	Moderate–good vigor

Table 4. Yield performance of shallot under different treatments

Treatment	Fresh Bulb Weight per Plot (kg)	Estimated Yield (t/ha)
T0 (control)	1.25 ± 0.08	6.25
T1 (low)	1.33 ± 0.07	6.65
T2 (medium)	1.47 ± 0.06	7.35
T3 (high)	1.37 ± 0.05	6.85

Implications for Sustainable Pest Management

The absence of severe phytotoxic effects across treatments (Table 5) indicates that *L. camara* extract is generally compatible with shallot cultivation when applied at appropriate concentrations. This supports its potential role as a component of sustainable pest management strategies, particularly within integrated pest management (IPM) frameworks that prioritize reduced reliance on synthetic pesticides.

Botanical pesticides align with sustainability objectives by offering biodegradable, locally available, and environmentally benign alternatives to conventional insecticides (Riyaz et al., 2021; Singh, 2024). International policy discussions on sustainable agriculture, including those promoted by the Food and Agriculture Organization, emphasize integrating such approaches to enhance agroecosystem resilience and reduce chemical inputs (Diyaolu & Folarin, 2024; Janker et al., 2018; Legg & Blandford, 2019).

Table 5. Phytotoxicity assessment

Treatment	Leaf Burn	Growth Inhibition	Overall Phytotoxicity
T0 (control)	None	None	None
T1 (low)	None	None	None
T2 (medium)	Very mild (temporary)	None	Negligible
T3 (high)	Mild leaf yellowing	Slight reduction in vigor	Low

Integration within Shallot-Based Cropping Systems

From a systems perspective, the results demonstrate that botanical pesticide application influences multiple components of the shallot-based cropping system, including pest population dynamics, plant vigor, and yield outcomes. Rather than acting as a standalone control measure, *L. camara* extract contributes to stabilizing crop performance under pest pressure, thereby supporting system-level productivity.

The observed balance between pest suppression and crop response underscores the need for context-specific evaluation of botanical pesticides within cropping systems. Integrating plant-derived insecticides with appropriate agronomic practices can enhance the sustainability of shallot production while maintaining economic viability (Ayilara et al., 2023; Souto et al., 2021; Zhou et al., 2024). Similar system-oriented conclusions have been drawn in agroecological studies emphasizing that sustainable pest management outcomes emerge from interactions among biological, agronomic, and management factors rather than single-input solutions (Gu et al., 2018; Zakka et al., 2019).

Synthesis of Findings

Overall, the integrated analysis of Tables 1–5 indicates that *L. camara* leaf extract, particularly at moderate concentrations, offers a promising strategy for sustainable pest management in shallot-based cropping systems. The findings highlight the potential of botanical pesticides to reduce pest pressure, improve crop vigor, and enhance yield while aligning with broader sustainability goals. These results reinforce the relevance of botanical pesticide applications as part of integrated and sustainable agricultural systems.

CONCLUSION

This study demonstrates that the application of botanical pesticides derived from *Lantana camara* leaves can effectively reduce *Spodoptera exigua* infestation in shallot-based cropping systems while supporting crop growth and yield performance. The results indicate a clear dose-dependent response, where moderate extract concentrations achieved an optimal balance between pest suppression and plant tolerance. These findings confirm that plant-derived insecticides can function as viable pest management tools within intensive horticultural systems, particularly under conditions where synthetic pesticide reliance poses ecological and agronomic risks.

Beyond pest control efficacy, the study highlights the systemic effects of botanical pesticide application on cropping system performance. Reduced pest pressure contributed to improved plant vigor and yield stability, while minimal phytotoxic effects at appropriate concentrations underscored the importance of dosage optimization. This integrated response illustrates that botanical pesticides should not be viewed as isolated inputs, but rather as functional components interacting with plant physiology, pest dynamics, and management practices within the cropping system.

Overall, the findings underscore the relevance of botanical pesticide applications in advancing sustainable pest management strategies for shallot production. By aligning pest control effectiveness with environmental compatibility and crop performance, botanical pesticides offer a pathway toward reducing chemical dependency while maintaining productivity. The study contributes

empirical evidence supporting the integration of locally available plant-based pest control measures into sustainable and resilient agricultural systems, reinforcing their potential role within broader frameworks of integrated and sustainable crop management.

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