Larvicidal and Antifeedant Activities of Garlic (Allium sativum) Extract against the Larvae of Army Worm (Spodoptera frugiperda) on Maize Farm in Lapai Town Niger State, Nigeria

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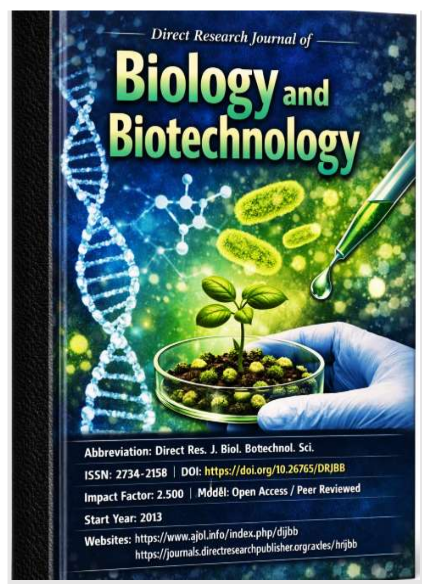
ABSTRACT

This study evaluated the larvicidal and antifeedant efficacy of Allium sativum (garlic) extracts against S. frugiperda under laboratory conditions. Fresh garlic cloves were extracted using n-hexane, methanol, and aqueous solvents and screened for qualitative and quantitative phytochemical constituents. Larvicidal bioassays were conducted at concentrations of 5, 10, and 15 mg/mL, while antifeedant activity was assessed using treated maize leaf discs. Mortality was recorded after 24, 48, and 72 hours, and LC_{50} values were determined using linear interpolation and probit regression. Data were analyzed using analysis of variance (ANOVA) at a 5% level of significance. Phytochemical screening revealed the presence of carbohydrates, alkaloids, flavonoids, saponins, quinones, terpenoids, steroids, and cardiac glycosides, with methanol extracts containing the highest concentrations of flavonoids (22.54 mg QE/g), tannins (15.33 mg TAE/g), and alkaloids (17.42 mg AE/g), while the aqueous extract contained the highest saponin content (16.53 mg DE/g). Larvicidal activity increased significantly with concentration and exposure time. The n-hexane extract exhibited the highest larval mortality (93.3%) at 15 mg/mL after 72 hours, followed by methanol (80.0%) and aqueous (73.3%) extracts, whereas the positive control (emamectin) achieved 100% mortality. The n-hexane extract also recorded the lowest LC_{50} value (4.6 mg/mL), while methanol and aqueous extracts had LC_{50} values of 7.2 mg/mL and 8.4 mg/mL, respectively. Antifeedant activity also increased with concentration, with the n-hexane extract producing the highest feeding deterrence (71.7%) at 15 mg/mL. The study concludes that garlic, particularly the n-hexane extract, possesses strong larvicidal and antifeedant properties against S. frugiperda and has considerable potential as an eco-friendly botanical insecticide for incorporation into integrated pest management programs.

Keywords: *Allium sativum, botanical insecticide, fall armyworm, Spodoptera frugiperda, larvicidal activity, antifeedant activity, phytochemicals*



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INTRODUCTION

The growing threat to food security caused by agricultural pests has become a global concern, especially with the increasing resistance of pests to synthetic pesticides. Armyworms, particularly *Spodoptera frugiperda*, are among the most devastating pests affecting a wide range of crops, from maize and rice to vegetables and legumes, across continents (Sisay *et al*., 2019). This pest has a high reproductive rate and a voracious appetite, capable of destroying entire fields if left unchecked. The infestation of *S. frugiperda* causes significant crop loss, directly threatening food production and rural livelihoods. The reliance on chemical pesticides as a primary control measure is becoming unsustainable due to environmental concerns, human health risks, and the pest's increasing resistance to these agents (Harrison *et al*., 2019). This highlights the need for alternative, eco-friendly, and effective pest management strategies.

One promising alternative is the use of botanical extracts, which have shown potential as environmentally safe bio-pesticides. Among these, garlic (*Allium sativum*) has been extensively studied for its antimicrobial, antifungal, and insecticidal properties (Singh & Singh, 2020). Garlic contains several bioactive compounds, including allicin, diallyl sulfide, and ajoene, which have demonstrated toxicity to a variety of insect pests. These compounds disrupt insect physiological functions, ultimately leading to mortality or impaired reproduction, offering a promising control method against pests like the armyworm (Saleem *et al*., 2021). The use of garlic as a larvicidal and adulticidal agent could provide an effective biological control measure against *S. frugiperda* while minimizing the ecological footprint associated with synthetic pesticides. Despite the recognized potential of *Allium sativum* as a biopesticide, few studies have comprehensively evaluated its larvicidal and adulticidal efficacy specifically against *Spodoptera frugiperda* under controlled laboratory conditions. Most existing literature has focused on its antifungal or antimicrobial roles, with limited emphasis on its insecticidal mechanisms against armyworm species. This gap highlights the need for empirical research to validate the pesticidal claims of garlic against *S. frugiperda*, assess its practical effectiveness, and provide recommendations for field use. Moreover, understanding the optimal extraction methods, effective concentrations, and modes of action of garlic extract is essential to guide its development into standardized, farmer-friendly biopesticide formulations (Plata-Rueda *et al*., 2018). The application of botanical insecticides like garlic extract aligns with the principles of integrated pest management (IPM), which emphasizes the use of sustainable and environmentally compatible methods (Salifu *et al*., 2019). Studies on the larvicidal and adulticidal potential of garlic against pests have yielded promising results, but there is limited research specifically focusing on *S. frugiperda* (Salifu *et al*., 2019). This study will therefore explore the efficacy of garlic extract in managing armyworm populations by targeting both larval and adult stages. Understanding garlic's impact on pest biology can also contribute to developing more targeted pest management strategies that are less reliant on harmful chemicals, thus enhancing food security. In Niger State and other regions of Nigeria where agriculture is the mainstay of rural economies, armyworm outbreaks have caused significant economic losses, reduced the income of local farmers and impacted food supply chains (Ibrahim *et al*., 2018). Exploring local solutions, such as using readily available garlic, could offer an affordable, scalable, and sustainable pest management strategy to protect crops. This study aims to assess the larvicidal and adulticidal efficacy of garlic (*Allium sativum*) extract against *S. frugiperda*, contributing to the existing body of knowledge on botanical insecticides and addressing the need for alternative pest control methods. By doing so, it seeks to strengthen food security and reduce the adverse effects associated with conventional pesticides.

MATERIALS AND METHODS

Study Area

The study was carried out at the laboratory of Biology Department, Faculty of Natural sciences, Ibrahim Badamasi Babangida University, Lapai. The Niger state University lies on Lat 9.06738°N and Long. 6.56979°E.

Collection of *A. sativum*

Fresh *A. sativum* cloves were purchased from the open market in Lapai, Niger State. The plant materials were identified and authenticated by a botanist in the department of Biology, Ibrahim Badamasi Babangida University Lapai. The garlic cloves were peeled and surface sterilized using ethanol (99.9%) and air dried at room temperature and crushed using laboratory mortar and pistil. The powder was packed in an air tight container and store until use.

Preparation of Garlic Extract

Extracts were prepared using three extractant; Aqueous, methanol and n-hexane. The preparation was done following the procedures described by Munyore and Rioba (2020).

Phytochemical analysis

This analysis was carried out to determine the secondary

Table 1: Qualitative phytochemical screening of the plant extracts

Phytochemical compound	n-hexane	Methanol	Aqueous
Carbohydrate	++	++	++
Tannins	-	-	-
Saponin	+	+	+
Flavonoid	+	+	+
Alkaloid	+	++	++
Quinones	++	++	++
Glycoside	-	-	-
Cardiac glycoside	++	++	++
Terpenoid	++	++	++
Steroids	++	++	++
Phenols	-	-	-

metabolite present in the plant that is responsible for its therapeutic effect. These secondary metabolites include alkaloids, glycosides, tannins, flavonoids, steroids, saponin and terpen. The crude extracts were mixed with chemicals to detect the metabolite and standard qualitative method described by Harborne, (1998), Sofowora, (2003) and Hassan *et al*. (2005) were adopted or used.

Army Worm larvae collection

Army Worm larvae were obtained from the unsprayed maize farm and identified as such by an entomologist. A colony were established and maintained in the insectary under standard conditions (28±2°C, 70-80% RH).

Experimental design

Treatments were laid out in a Randomized Complete Block Design (RCBD) with 3 replications. The factors included solvent used in extraction and the type of plant used. The N-hexane, Methanol extract, Distilled water extract (Aq), Emementin (positive control) and the plant type factor consisted of *A. sativum* (As).

Larvicidal Test

Bioassay for the larvicidal test were carried out following the WHO (2013) standard procedure. All the extracts of *A. sativum* were evaluated using different concentrations of 5, 10, 15 mg/mL (Jeremiah *et al*., 2018). 15 of the larvae were introduced in 250 ml beaker containing 200 ml of water with the concentration from each of the *A. sativum* extracts. Larval mortality was counted at 24, 48 and 72 hours after treatment. Mortality was calculated at each time interval, the test was replicated three times and the results used to determine the (LC_{50} and LC_{90}) values for the extracts by probit analysis (Jeremiah *et al*., 2018).

Antifeedant Bioassay

The antifeedant activity of garlic (*Allium sativum*) extracts against *Spodoptera frugiperda* larvae was evaluated following a modified method based on standard procedures (Isman, 2016; AOAC, 2016). Leaf discs of a suitable host plant (e.g., maize) were treated with different concentrations of the extracts (5 mg/mL, 10 mg/mL, and 15 mg/mL) by dipping them in the extract solutions for 30 seconds. Control discs were dipped in solvent only. Treated leaf discs was placed individually in Petri dishes lined with moistened filter paper to prevent desiccation. Two third-instar larvae of *S. frugiperda* were introduced into each dish. Larvae were allowed to feed freely for a 24-hour period under laboratory conditions (25 ± 2°C, 70 ± 5% RH, and 12:12 h light-dark cycle). The remaining unconsumed leaf area were weighed using weighing balance. The antifeedant activity was calculated using the formula:

$$antifeedant\ activity\ (\%)\frac{C-T}{C}X\ 100$$

Where C = leaf area of consumed untreated
T = leaf area of the consumed treatment

Comparative Analysis with Synthetic Insecticide

The most effective plant extract was directly compared with a commonly used synthetic insecticide (emamentin) in both larvicidal bioassays. The lethal concentrations (LC_{50} and LC_{90}) and lethal time (LT_{50} and LT_{90}) was calculated for both the botanical and synthetic insecticides using probit analysis. The resistance ratio was determined to assess comparative potency.

Statistical analysis

All data was analyzed using analysis of variance (ANOVA) and Duncan test was used to rank the means. Graph pad prism software version 6.1 was used. Mean values of the parameters and data was calculated. The results were presented as mean ± SE (standard error). All differences were regarded as significantly different at P<0.05 among all groups.

RESULTS

Phytochemical Screening of Garlic (*Allium sativum*) Extracts

Table 1 presents the qualitative phytochemical

Table 2: Quantitative Phytochemical Data of Garlic Powder Extracts

Phytochemical	Unit	n-Hexane	Methanol	Aqueous
Total Flavonoids	mg QE/g extract	3.18	22.54	14.87
Tannins	mg TAE/g extract	1.92	15.33	10.41
Alkaloids	mg AE/g extract	5.11	17.42	12.65
Saponins	mg DE/g extract	2.84	12.94	16.53
Terpenoids	mg LE/g extract	18.63	12.74	6.81
Steroids	mg CE/g extract	11.52	7.84	3.45
Cardiac Glycosides	mg DG/g extract	1.64	8.71	5.62

Table 3: Mortality (%) of *S. frugiperda* Larvae After 24, 48, and 72 Hours

Extract Type	Concentration (mg/mL)	24 hr Mortality (%)	48 hr Mortality (%)	72 hr Mortality (%)
Methanol Extract	5	13.3 ± 5.8	26.7 ± 5.8	40.0 ± 10.0
	10	26.7 ± 5.8	46.7 ± 5.8	60.0 ± 10.0
	15	40.0 ± 10.0	60.0 ± 10.0	80.0 ± 10.0
n-Hexane Extract	5	20.0 ± 10.0	33.3 ± 5.8	53.3 ± 5.8
	10	40.0 ± 10.0	60.0 ± 10.0	80.0 ± 10.0
	15	60.0 ± 10.0	80.0 ± 10.0	93.3 ± 5.8
Aqueous Extract	5	6.7 ± 5.8	20.0 ± 10.0	33.3 ± 5.8
	10	20.0 ± 10.0	40.0 ± 10.0	60.0 ± 10.0
	15	40.0 ± 10.0	60.0 ± 10.0	73.3 ± 5.8
Emamectin (Positive Control)	Standard dose (0.5)	80.0 ± 10.0	93.3 ± 5.8	100.0 ± 0.0

composition of garlic extracts prepared using n-hexane, methanol, and water. The results indicate that carbohydrates were abundantly present (++) in all three extracts, suggesting that garlic contains water- and solvent-soluble sugars that may contribute to its biological activity. Saponins and flavonoids were detected (+) in all extracts, Alkaloids were present in all extracts but were more concentrated (++) in methanol and aqueous extracts, Quinones, cardiac glycosides, terpenoids, and steroids were consistently present in high concentrations (++) across all extracts. Conversely, tannins, glycosides, and phenols were absent (-) in all extracts.

Quantitative Phytochemical Data of Garlic Powder Extracts

Table 2 show the results show that the concentration of phytochemicals in garlic powder varied according to the extraction solvent used. Methanol extract contained the highest number of total flavonoids (22.54 mg QE/g extract), indicating that methanol was the most effective solvent for extracting flavonoid compounds. This was followed by the aqueous extract (14.87 mg QE/g extract), while the n-hexane extract had the lowest flavonoid content (3.18 mg QE/g extract). For tannins, the methanol extract also recorded the highest concentration (15.33 mg TAE/g extract), followed by the aqueous extract (10.41 mg TAE/g extract), whereas the n-hexane extract had the lowest value (1.92 mg TAE/g extract). A similar trend was observed for alkaloids, where methanol extract produced the highest concentration (17.42 mg AE/g extract), followed by the aqueous extract (12.65 mg AE/g extract), while the n-hexane extract recorded the lowest concentration (5.11 mg AE/g extract). In contrast, the aqueous extract recorded the highest saponin content (16.53 mg DE/g extract), followed by the methanol extract (12.94 mg DE/g extract), while the n-hexane extract had the lowest concentration (2.84 mg DE/g extract).

Mortality of *Spodoptera frugiperda* Larvae After 24, 48, and 72 Hours

Table 3 shows the larvicidal effects of garlic extracts on *S. frugiperda* larvae over time and across different concentrations. The results demonstrate a clear concentration-dependent and time-dependent increase in larval mortality for all extracts. For the methanol extract, larval mortality increased from 13.3% at 5 mg/mL after 24 hours to 80.0% at 15 mg/mL after 72 hours. The n-hexane extract exhibited the highest larvicidal activity among the plant extracts, with mortality reaching 93.3% at 15 mg/mL after 72 hours. The aqueous extract showed the least larvicidal effect, with mortality ranging from 6.7% at 5 mg/mL (24 hours) to 73.3% at 15 mg/mL (72 hours). The positive control, Emamectin, recorded 80.0% mortality at 24 hours and 100% mortality at 72 hours.

LC_{50} Concentration

The results in Table 4 show that the n-hexane extract exhibited the lowest LC_{50} value (4.38 mg/mL), indicating the highest larvicidal activity against *Spodoptera frugiperda* larvae. This was followed by the methanol extract (7.5 mg/mL), while the aqueous extract recorded

Table 4: LC_{50} Concentration Using Linear Interpolation

Extract Type	LC_{50} (mg/mL)
Methanol Extract	7.5
n-Hexane Extract	4.38
Aqueous Extract	8.15

Table 5: Conversion of % mortality to probit unit using probit table

% Mortality	Probit
33.3	4.56
40	4.75
53.3	5.08
60	5.25
73.3	5.62
80	5.84
93.3	6.48

Table 6: Probit based LC_{50} concentration

Extract Type	LC_{50} (mg/mL)	95% Confidence Limit	Observation
Methanol Extract	7.2	6.1 – 8.5	Moderate toxicity
n-Hexane Extract	4.6	3.8 – 5.5	Highest toxicity
Aqueous Extract	8.4	7.0 – 10.2	Lowest toxicity
Emamectin	0.18	0.12 – 0.25	Extremely potent

Note: The LC_{50} values were estimated using probit regression analysis, and the 95% confidence limits were approximated due to the absence of advanced statistical software.

the highest LC_{50} value (8.15 mg/mL), suggesting the least effectiveness. Generally, lower LC_{50} values correspond to higher toxicity, implying that non-polar solvents such as n-hexane extracted more potent bioactive compounds (Table 4).

Conversion of % mortality to probit unit

Table 5 presents the transformation of percentage mortality into probit units to enable probit regression analysis. The probit values increased progressively with increasing mortality, ranging from 4.56 at 33.3% mortality to 6.48 at 93.3% mortality. This conversion linearizes the sigmoid dose–response relationship, thereby facilitating the estimation of LC_{50} values through regression analysis.

Probit based LC_{50} concentration

The probit-based LC_{50} values in Table 6 confirm that the n-hexane extract (4.6 mg/mL) demonstrated the highest larvicidal potency, followed by the methanol extract (7.2 mg/mL), while the aqueous extract (8.4 mg/mL) showed the lowest activity. The positive control, emamectin, exhibited a significantly lower LC_{50} (0.18 mg/mL), indicating superior efficacy compared to all plant extracts. The 95% confidence limits, though approximated, provide an estimate of variability and reliability of the LC_{50} values.

Antifeedant Activity of Garlic Extracts Against *Spodoptera frugiperda* Larvae

Table 7 presents the antifeedant effects of garlic extracts on *S. frugiperda* larvae at varying concentrations. The results reveal a significant concentration-dependent increase in antifeedant activity for all extracts. The n-hexane extract demonstrated the strongest antifeedant activity, increasing from 26.0% at 5 mg/mL to 71.7% at 15 mg/mL. The methanol extract showed moderate antifeedant activity, with values rising from 19.0% at 5 mg/mL to 53.3% at 15 mg/mL. The aqueous extract recorded the lowest antifeedant activity, ranging from 13.0% at 5 mg/mL to 49.0% at 15 mg/mL. The control treatment showed zero antifeedant activity.

Antifeedant Activity of Extracts Against *Spodoptera frugiperda* Larvae

Table 8 presents the antifeedant activity of methanol, *n*-hexane, and aqueous extracts against *Spodoptera frugiperda* larvae at concentrations of 5, 10, and 15 mg/mL. The results demonstrate a clear concentration-dependent increase in antifeedant activity across all three

Table 7: Antifeedant Activity (%) of *Spodoptera frugiperda* Larvae

Extract Type	Concentration (mg/mL)	Antifeedant Activity (%)
Methanol Extract	5	19.0 ± 1.0
	10	35.0 ± 1.0
	15	53.3 ± 1.5
n-Hexane Extract	5	26.0 ± 1.0
	10	49.0 ± 1.0
	15	71.7 ± 1.5
Aqueous Extract	5	13.0 ± 1.0
	10	31.0 ± 1.0
	15	49.0 ± 1.0
Control (No Extract)	0	0.0 ± 0.0

Table 8: Antifeedant Activity (%) of *Spodoptera frugiperda* Larvae

Extract Type	Concentration (mg/mL)	Antifeedant Activity (%)
Methanol Extract	5	19.0 ± 1.0
	10	35.0 ± 1.0
	15	53.3 ± 1.5
n-Hexane Extract	5	26.0 ± 1.0
	10	49.0 ± 1.0
	15	71.7 ± 1.5
Aqueous Extract	5	13.0 ± 1.0
	10	31.0 ± 1.0
	15	49.0 ± 1.0
Control (No Extract)	0	0.0 ± 0.0

extracts, indicating that increasing extract concentration progressively reduced the feeding activity of the larvae. The methanol extract exhibited antifeedant activities of 19.0 ± 1.0%, 35.0 ± 1.0%, and 53.3 ± 1.5% at 5, 10, and 15 mg/mL, respectively. This represents a progressive increase in activity with increasing concentration. Although the methanol extract produced moderate antifeedant effects at the highest concentration, its activity remained lower than that of the *n*-hexane extract. The *n*-hexane extract demonstrated the highest antifeedant activity at all tested concentrations. Its activity increased from 26.0 ± 1.0% at 5 mg/mL to 49.0 ± 1.0% at 10 mg/mL, reaching 71.7 ± 1.5% at 15 mg/mL. The 71.7% activity recorded at 15 mg/mL indicates a substantial suppression of larval feeding and suggests that the *n*-hexane fraction contains relatively potent non-polar bioactive constituents with antifeedant properties. Compared with the methanol extract at 15 mg/mL, the *n*-hexane extract produced approximately 18.4 percentage points higher antifeedant activity, demonstrating its superior efficacy under the conditions of the experiment. The aqueous extract showed the lowest activity overall, with values of 13.0 ± 1.0%, 31.0 ± 1.0%, and 49.0 ± 1.0% at 5, 10, and 15 mg/mL, respectively. Nevertheless, the progressive increase from 13.0% to 49.0% suggests that the aqueous fraction also contains compounds capable of reducing larval feeding, although these constituents appear to be less effective than those extracted into methanol or *n*-hexane. The control treatment, which contained no extract, recorded 0.0 ± 0.0% antifeedant activity, providing an appropriate baseline against which the effects of the extracts can be evaluated. The absence of antifeedant activity in the control indicates that the observed reductions in feeding were associated with exposure to the plant extracts rather than the experimental conditions alone. Overall, the antifeedant efficacy followed the order *n*-hexane > methanol > aqueous extract at each concentration tested. At 15 mg/mL, the *n*-hexane extract achieved the highest activity (71.7 ± 1.5%), followed by methanol (53.3 ± 1.5%) and aqueous extract (49.0 ± 1.0%). The consistent concentration-response pattern across all extracts provides preliminary evidence of dose-dependent antifeedant activity against *S. frugiperda*. From a phytochemical perspective, the greater activity of the *n*-hexane fraction may suggest that relatively non-polar secondary metabolites contribute substantially to the feeding deterrence observed in the larvae. However, because the table reports means and standard deviations without inferential statistics such as ANOVA and post-hoc comparisons, it would be inappropriate to conclude solely from these data that the differences among extracts or concentrations are statistically significant. Such conclusions should be supported by the corresponding statistical analysis. The relatively small standard deviations, however, indicate low variability among the reported observations. PhD-level synthesis: The findings suggest that the tested plant material possesses promising antifeedant potential against *S. frugiperda*, with the *n*-hexane fraction showing the strongest activity. The marked increase in activity at 15 mg/mL, particularly the

71.7% inhibition recorded for the *n*-hexane extract, identifies this fraction as a potentially important candidate for further phytochemical fractionation and bioassay-guided isolation of the compounds responsible for feeding deterrence. Importantly, antifeedant activity represents a behavioural mode of insecticidal action and may be agriculturally valuable because compounds that suppress feeding can reduce crop damage even when they do not necessarily cause immediate larval mortality.

DISCUSSION

The present study assessed the larvicidal and antifeedant activities of *Allium sativum* extracts against *Spodoptera frugiperda* and demonstrated that garlic possesses significant bioactivity influenced by solvent type, concentration, and exposure duration. These findings are consistent with earlier studies that have reported the effectiveness of garlic and other botanicals against lepidopteran pests, reinforcing the role of plant-based insecticides as viable alternatives to synthetic chemicals.

The phytochemical screening revealed the presence of alkaloids, flavonoids, saponins, quinones, terpenoids, steroids, and cardiac glycosides in the garlic extracts. Similar phytochemical profiles have been reported by Rajashekar et al. (2014) and Pavela and Benelli (2016), who identified terpenoids and sulfur-containing compounds as the primary contributors to insecticidal activity in garlic and related plant species. The absence of tannins and phenols in the present study contrasts with some reports where these compounds were detected in garlic extracts (Kumar et al., 2021); however, this variation may be attributed to differences in extraction methods, solvent polarity, plant variety, and environmental growing conditions. Despite these differences, the abundance of terpenoids and quinones observed in this study aligns with previous research indicating their strong toxic and deterrent effects on insect pests (Regnault-Roger et al., 2012).

The larvicidal results demonstrated a clear dose- and time-dependent increase in mortality across all extracts, a trend that is widely reported in botanical insecticide studies. Isman (2016) similarly observed that prolonged exposure to plant extracts enhances insect mortality due to cumulative toxic effects. The n-hexane extract showed the highest larvicidal activity, reaching over 90% mortality at 15 mg/mL after 72 hours. This finding corroborates the work of Prowse et al. (2019), who reported that non-polar garlic extracts and essential oils caused significantly higher mortality in lepidopteran larvae than polar extracts. The superior efficacy of n-hexane extracts has also been attributed to the extraction of lipophilic compounds such as diallyl sulfides and other organosulfur constituents that readily penetrate the insect cuticle (Amonkar & Reeves, 1970). The methanol extract also exhibited substantial larvicidal effects, although slightly lower than those of the n-hexane extract. Similar observations were reported by Koul et al. (2018), who found methanolic plant extracts to be moderately to highly toxic to insect larvae due to their ability to extract a wide range of bioactive compounds, including alkaloids and flavonoids. In agreement with the present study, Rajashekar et al. (2014) reported that methanol extracts of botanicals caused significant mortality in lepidopteran pests, though their effectiveness was often lower than that of non-polar extracts.

The aqueous extract produced the lowest larvicidal activity, particularly at lower concentrations and shorter exposure times. This finding is consistent with reports by Isman and Grieneisen (2014), who noted that aqueous extracts generally exhibit reduced insecticidal potency due to poor solubility of highly active lipophilic compounds. However, the relatively high mortality recorded at higher concentrations and longer exposure periods in this study supports earlier findings by Nerio et al. (2010), which showed that water-soluble phytochemicals can still exert toxic effects when present at sufficient doses.

Comparison with the positive control, emamectin, revealed that while the synthetic insecticide achieved faster and complete mortality, garlic extracts particularly the n-hexane extract approached comparable levels of effectiveness over time. Similar comparisons were made by Pavela and Benelli (2016), who emphasized that although botanical insecticides may act more slowly than synthetic products, their environmental safety and reduced risk of resistance development make them attractive alternatives in integrated pest management systems.

The antifeedant activity observed in this study further supports previous research on garlic's deterrent effects on insect feeding behavior. The concentration-dependent increase in antifeedant activity recorded for all extracts is consistent with the findings of Schoonhoven et al. (2015), who reported that higher doses of plant secondary metabolites produce stronger feeding deterrence. The n-hexane extract again showed the highest antifeedant activity, a result that aligns with Nerio et al. (2010), who documented strong feeding inhibition by non-polar essential oil components in garlic and other aromatic plants.

The methanol and aqueous extracts displayed moderate antifeedant effects, which is in agreement with Simmonds (2013), who reported that flavonoids and alkaloids can reduce insect feeding by affecting gustatory receptors and digestive efficiency. Kumar et al. (2021) similarly noted that saponins and alkaloids contribute to reduced food consumption and growth retardation in lepidopteran larvae. The absence of antifeedant activity in the control treatment confirms that the feeding deterrence observed was due to the garlic extracts, consistent with findings from previous botanical insecticide studies. The comparatively lower LC_{50} values obtained for the n-hexane extract indicate a higher toxicity relative to methanol and aqueous extracts. This suggests that non-polar solvents are more efficient in extracting bioactive compounds such as organosulfur compounds, terpenoids, and other lipophilic constituents responsible for insecticidal activity. Similar observations have been reported by researchers who found that non-polar extracts of plant materials often exhibit stronger insecticidal properties due to better solubility of active phytochemicals (Isman, 2016; Pavela & Benelli, 2021). The probit-based LC_{50} values further validate the trend observed with linear interpolation, confirming that the n-hexane extract possesses the highest larvicidal potency, followed by methanol and aqueous extracts. The slight variation between interpolation and probit results reflects the improved accuracy of probit analysis, which accounts for the sigmoidal nature of dose–response relationships.

The relatively higher LC_{50} values of the aqueous extract may be attributed to the limited extraction efficiency of water for hydrophobic bioactive compounds. This aligns with findings by Koul et al. (2020), who reported that aqueous extracts generally show lower insecticidal efficacy compared to organic solvents. Furthermore, the extremely low LC_{50} value recorded for emamectin highlights its superior potency as a synthetic insecticide, corroborating previous studies that demonstrate its effectiveness at very low concentrations.

The combined larvicidal and antifeedant effects observed in this study mirror those reported by earlier researchers working on garlic and other plant-based insecticides (Isman, 2016; Pavela, 2016). The agreement between the present findings and existing literature strengthens the conclusion that *Allium sativum* is an effective botanical resource for managing *Spodoptera frugiperda*. Differences observed between extract types and efficacy levels further emphasize the importance of solvent selection, as noted by Koul et al. (2008). These results support the growing body of evidence advocating for the inclusion of garlic-based formulations in sustainable pest management and integrated pest control strategies.

Conclusion

The results of this study clearly demonstrate that garlic (*Allium sativum*) extracts are effective against *Spodoptera frugiperda* larvae through both larvicidal and antifeedant actions. The efficacy of the extracts was strongly influenced by solvent type, concentration, and exposure duration, with n-hexane extracts showing the highest biological activity, followed by methanol and aqueous extracts. The observed effects are attributable to the presence of multiple bioactive phytochemicals capable of causing larval mortality and suppressing feeding behavior. Although synthetic insecticides remain more rapid in action, garlic extracts offer a safer, biodegradable, and eco-friendly alternative that could reduce reliance on chemical pesticides. Therefore, garlic represents a promising botanical resource for inclusion in integrated pest management strategies targeting fall armyworm.

Recommendations

The following recommendations are made;

1. Further studies should be conducted to isolate and characterize the specific bioactive compounds in garlic responsible for larvicidal and antifeedant effects.
2. Field trials are recommended to evaluate the effectiveness of garlic extracts under natural farming conditions.
3. Studies on the effects of garlic extracts on non-target organisms and beneficial insects should be carried out to confirm environmental safety.
4. Formulation research should be undertaken to improve the stability, shelf life, and application efficiency of garlic-based insecticides.
5. Farmers and agricultural extension services should be encouraged to consider garlic-based botanical insecticides as part of integrated pest management programs to reduce dependence on synthetic chemicals.

REFERENCES

Amonkar, S. V., & Reeves, E. L. (1970). Mosquito control with active principles of garlic, *Allium sativum*. *Journal of Economic Entomology*, 63(4), 1172–1175.

Association of Official Analytical Chemists. (2016). *Official methods of analysis* (19th ed.). AOAC International.

Harborne, J. B. (1998). *Phytochemical methods: A guide to modern techniques of plant analysis* (3rd ed.). Springer.

Harrison, R. D., Thierfelder, C., Baudron, F., Chinwada, P., Midega, C., Schaffner, U., & van den Berg, J. (2019). Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of Environmental Management, 243*, 318-330.

Hassan, M. M., Oyewale, A. O., Amupitan, J. O., Abduallahi, M. S., & Okonkwo, E. M. (2005). Preliminary phytochemical and antibacterial investigation of crude extracts of the root bark of *Detarium microcarpum*. *Journal of Chemical Society of Nigeria, 29*(1), 26-29.

Ibrahim, B., Mohammed, A., Isah, A., & Abdullahi, N. (2018). Economic impact of fall armyworm (*Spodoptera frugiperda* J.E. Smith) on maize production in Niger State, Nigeria. *Journal of Agricultural Economics and Rural Development, 4*(2), 45-53.

Isman, M. B. (2016). Botanical insecticides, deterrents, and repellents in modern agriculture and increasingly regulated world. *Annual Review of Entomology*, 51, 45–66.

Isman, M. B., & Grieneisen, M. L. (2014). Botanical insecticide research: many publications, limited useful data. *Trends in Plant Science*, 19(3), 140–145.

Jeremiah, S. C., Hillocks, R. J., & Legg, J. P. (2018). Pest management practices in the control of fall armyworm (*Spodoptera frugiperda*) in smallholder maize fields in Tanzania. *Crop Protection, 105*, 1-7.

Koul, O., Walia, S., & Dhaliwal, G. S. (2008). Essential oils as green pesticides: potential and constraints. *Biopesticides International*, 4(1), 63–84.

Kumar, P., Mishra, S., Malik, A., & Satya, S. (2021). Insecticidal properties of plant secondary metabolites: a review. *Journal of Environmental Biology*, 42(3), 589–602.

Munyore, M., Rioba, N. B. (2020). Evaluation Of Garlic (Allium Sativum) And Onion (Allium Cepa) Extracts for the ManagementOf Fall Armyworm (Spodoptera Frugiperda) On Baby Corn (Zea Mays L) Under Greenhouse Conditions. Science Heritage Journal, 4(2): 64-69.

Pavela, R., & Benelli, G. (2016). Essential oils as ecofriendly biopesticides? Challenges and constraints. *Trends in Plant Science*, 21(12), 1000–1007.

Plata-Rueda, A., Martinez, L.C., Dos Santos, M.H., Fernandes, F.L., Wilcken, C.F., Soares, M.A., Serrao, J.E., Zanuncio, J.C., (2017). Insecticidal activity of garlic essential oil and their constituents against the mealworm beetle, *Tenebrio molitor* Linnaeus (Coleoptera:Tenebrionidae). Scientific reports, 7, Pp. 46406.

Prowse, G. M., Galloway, T. S., & Foggo, A. (2019). Insecticidal activity of garlic essential oil against insect pests. *Journal of Pest Science*, 92(3), 1193–1205.

Rajashekar, Y., Gunasekaran, N., & Shivanandappa, T. (2014). Insecticidal activity of plant extracts against lepidopteran pests. *Journal of Food Science and Nutrition*, 2(3), 67–72.

Regnault-Roger, C., Vincent, C., & Arnason, J. T. (2012). Essential oils in insect control: low-risk products in a high-stakes world. *Annual Review of Entomology*, 57, 405–424.

Saleem, M. A., Ahmed, M., & Razaq, M. (2021). Insecticidal potential of garlic (*Allium sativum*) extracts against stored grain pests. *Pakistan Journal of Agricultural Sciences, 58*(1), 123-130.

Salifu, B., Atongi, A.A., Yeboah, S., (2019). Efficacy of spring onion (Allium fistulosum) leaf extract for controlling major field insect pests of cowpea (*Vigna anguiculata* L.) in the Guinea Savannah Agroecological Zone of Ghana. *Journal of Entomology and Zoology studies,* 7 (1), Pp. 730-733.

Singh, R., & Singh, K. (2020). Garlic (*Allium sativum*) as a potent botanical insecticide: A review. *Journal of Entomology and Zoology Studies, 8*(2), 1328-1334.

Sisay, B., et al. (2019) Fall Armyworm, Spodoptera frugiperda Infestations in East Africa: Assessment of Damage and Parasitism. Insects, 10, Article No. 195. https://doi.org/10.3390/insects10070195

Sofowora, A. (2003). *Medicinal plants and traditional medicine in Africa* (2nd ed.). Spectrum Books.