

Nematicidal Activity of Aqueous and Ethanolic Leaf Extracts of *Azadirachta indica* (A. Juss.) and *Senna alata* (L.) Roxb. against *Meloidogyne* Species on Tomato

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ABSTRACT

Root-knot nematode (*Meloidogyne* spp.) is a serious constraint to tomato production, and reliance on chemical nematicides poses environmental and health concerns. This study investigated the phytochemical composition and nematicidal potential of *Azadirachta indica* and *Senna alata* leaf extracts against root-knot nematode second-stage juveniles (J2) under laboratory and field conditions. Though neem (*Azadirachta indica*) is widely studied, senna (*Senna alata* or related species) is less explored in nematode control. The fresh leaves of both plants were shade-dried, pulverized, and extracted using aqueous and ethanolic solvents by cold maceration. Phytochemical constituents were screened qualitatively; while nematicidal assays were carried out by exposing approximately 100 J2 to graded concentrations of extracts (0.625–5.0 mg/ml) using Complete Randomized Design (CRD). Mortality was recorded at 6-hours intervals up to 24 hours, with distilled water as control. Field trials were conducted on nematode-infested tomato plots laid out in a Randomized Complete Block Design (RCBD). Treatments consisted of different extract concentrations (1 ml) of 30 mg/ml, 45 mg/ml, and 60 mg/ml were applied to soil at transplanting. Parameters assessed included root gall index, J2 population density, and fruit yield. Data generated were subjected to ANOVA using Statistical package for social sciences (SPSS) and means separated at $p \leq 0.05$. Phytochemical screening revealed variations in metabolite distribution. *Azadirachta indica* aqueous extracts contained abundant saponins, tannins, and phenols, whereas ethanolic extracts were rich in tannins, flavonoids, and glycosides. *S. alata* exhibited broader profiles, with high levels of alkaloids, flavonoids, tannins, phenols, anthraquinones, and steroids. Laboratory assays showed strong concentration- and time-dependent mortality, with *S. alata* extracts achieving 100 % mortality within 12–18 hours at 5 mg/ml, while *A. indica* required up to 18–24 hours. Field studies confirmed significant suppression of galling and J2 density, alongside improved yields. At 5 mg/ml, both species reduced gall index to below 1.0, suppressed J2 by over 90 %, and increased tomato yield above $31 \text{ t}\cdot\text{ha}^{-1}$ compared to $18 \text{ t}\cdot\text{ha}^{-1}$ in control. In conclusion, *A. indica* and *S. alata* possess potent nematicidal properties, with *S. alata* acting more rapidly. The field trial demonstrated the potential of *Azadirachta indica* and *Senna alata* as eco-friendly bio-nematicides for sustainable tomato production.

Keywords: *Meloidogyne*, Phytochemical, Nematicidal Assay



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INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated and economically important vegetable crop globally, valued for its nutritional content, versatility, and industrial applications. It is rich in vitamins (A, C, and E), minerals, antioxidants such as lycopene, and serves as a major source of income to farmers in both developed and developing countries (Sambo *et al.*, 2024). In Nigeria, tomato production plays a crucial role in food security and rural livelihoods; however, its productivity is significantly constrained by several biotic factors, particularly plant-parasitic nematodes. Among these, root-knot nematodes belonging to the genus *Meloidogyne* are the most destructive. These obligate endoparasites infect plant roots, inducing the formation of characteristic galls that interfere with water and nutrient uptake, leading to stunted growth, chlorosis, wilting, and substantial yield losses (Sharf *et al.*, 2025). Globally, yield losses due to *Meloidogyne* spp. in tomato production range from 20–50%, while in tropical regions such as Nigeria, losses can exceed 45% under severe infestation (Sambo *et al.*, 2024). The persistence and widespread distribution of *Meloidogyne* spp. are attributed to their high reproductive capacity, broad host range, and ability to survive in soil as eggs or juveniles under unfavorable conditions. Their management has largely relied on synthetic nematicides (Furadan); however, these chemical poses serious environmental, health, and economic concerns, including soil toxicity, groundwater contamination, and the development of resistant pest populations (Sharf *et al.*, 2025). Consequently, there is increasing interest in sustainable, eco-friendly alternatives such as botanical nematicides. Botanical extracts derived from plants with pesticidal properties have gained prominence due to their biodegradability, low toxicity to non-target organisms, and affordability for smallholder farmers (Hussain *et al.*, 2023). Among such plants, *Azadirachta indica* (neem) has been extensively studied and widely recognized for its potent bioactive compounds, including azadirachtin, nimbin, and salannin, which exhibit strong nematicidal, insecticidal, and antimicrobial properties (Sharf *et al.*, 2025). Neem-based formulations have been reported to significantly reduce nematode populations and improve crop performance.

In contrast, *Senna alata* (L.) Roxb., although known for its medicinal and pesticidal properties, remains underexplored in nematode management. The plant contains important phytochemicals such as anthraquinones, flavonoids, alkaloids, and tannins, which have demonstrated antimicrobial and antiparasitic activities (Ezeonu *et al.*, 2023). Preliminary studies suggest that *S. alata* may possess nematicidal potential however; comprehensive comparative studies with established botanicals like neem are limited. Additionally, a factor influencing the efficacy of plant extracts is the method of extraction and the solvent type both of which plays a significant role in determining the quantity and

nature of phytochemicals extracted. Aqueous extracts are more accessible and cost-effective for farmers, whereas organic solvents such as ethanol often yield higher concentrations of bioactive compounds (Hussain *et al.*, 2023). Despite this, there is limited comparative information on the effectiveness of aqueous versus ethanolic extracts of these plants under similar experimental conditions. Moreover, most existing studies focus primarily on laboratory assays, with fewer investigations extending to field validation and agronomic performance. Inadequate integration of nematode suppression data with plant growth and yield parameters also exist, which is essential for practical agricultural application. In Nigeria and other tropical regions, root-knot nematodes (*Meloidogyne* spp.) continue to pose a serious threat to tomato production, leading to significant yield losses and reduced crop quality. Although botanical alternatives such as neem have been widely studied, there is still limited information on the comparative efficacy of different plant species and extraction methods. In particular, *Senna alata* remains underutilized despite its rich phytochemical composition and potential pesticidal properties. Additionally, there is insufficient data comparing aqueous and ethanolic extracts of these plants under both laboratory and field conditions. This gap in knowledge limits the development of cost-effective, environmentally friendly, and locally adaptable nematode management strategies. Therefore, there is a need to investigate and compare the nematicidal efficacy of aqueous and ethanolic leaf extracts of *Azadirachta indica* and *Senna alata* against *Meloidogyne* spp. infecting tomato.

Aim of the Study

The aim of this study is to evaluate the nematicidal activity of aqueous and ethanolic leaf extracts of *Azadirachta indica* and *Senna alata* against root-knot nematodes (*Meloidogyne* spp.) infecting tomato.

The specific objectives are to:

- (i) Determine the phytochemical constituents of aqueous and ethanolic leaf extracts of *Azadirachta indica* and *Senna alata*.
- (ii) Evaluate the *in vitro* nematicidal effects of the extracts on second-stage juveniles (J2) of *Meloidogyne* spp.
- (iii) Assess the effect of the extracts on root galling, nematode population density, and tomato yield under field conditions.

MATERIALS AND METHODS

Test Sample Collection

Fresh leaves of *Azadirachta indica* and *Senna alata* were

collected from Pandam village of Qua'anpan LGA of Plateau State. The plant collection was done in February, 2025 and was conveyed to the Department of Plant Science and Biotechnology, University of Jos for identification and analyses.

Test Sample Preparation

The fresh leaves collected were washed with sterile distilled water and rinsed in 5% hypochlorite in three changes of water for surface decontamination. The washed samples were shed-dried on a laboratory bench at room temperature of $27\pm 2^{\circ}\text{C}$ until completely dried to constant weight. This was followed by pulverization with sterile laboratory pestle and mortar. The pulverized samples were separately sieved with a 0.05 mm mesh size sieve. The leaf powder of each plant was kept in an air-tight bottle until required for use.

Extraction of the Plant Material

The extraction was carried using cold maceration method at the ratio 1:10 grams to volume of water and ethanol. Fifty grams each, of the powder was weighed using a top loading balance which was transferred into a large extracting flask (bottles) the content was soaked with 500 ml of water and ethanol (separately) and allowed to stand for three (3) days at room temperature with constant agitation at intervals. The suspension was filtered with a sterile muslin cloth and then filtered again using sterile Whatman No.1 filter paper inserted in a funnel. The plant residue was subjected to several parts of rinsing and filtration to attain an exhaustive level of extraction.

Phytochemical Analysis of Extract

The extracts were subjected to phytochemical screening to determine the presence of alkaloids, carbohydrates, flavonoids, saponins, tanins, glycosides, (cardiac, steroidal), terpenes/terpenoids, fatty acids, resins using procedures described by Dawen *et al.* (2024) with slight modification.

Sourcing and Isolation of Root-Knot Nematodes

Heavily galled tomato roots, symptomatic of root-knot nematode infection, were collected from various irrigation fields in Farin-Gada Jos North, Plateau State, for the isolation of root knot nematodes. Root-knot nematode from infected tomato was isolated using the modified Baermann Funnel method of nematode extraction Okechalu, *et al.*, (2020). The galls from the tomato roots were placed in Petri-dishes containing a small amount of distilled water to moisten them and then teased apart. The root samples and distilled water in the Petri-dishes were inverted into funnels with a short piece of rubber tubing, attached to the stem. A test tube filled with water

was then attached to the end of the rubber tubes which was made air-tight at the points of attachment using masking tape. The funnels were lined up with thin layer of cotton wool and supported in an upright position. The root samples in the funnel were watered to prevent them from drying therefore, allowing for free movement of nematodes. The set up was allowed to stand for 48 hours. Nematodes juveniles that hatched and swam through the cotton wool were collected at the bottom of the test tube. These were kept properly for nematode population estimation and *in vitro* studies.

Multiplication of Inoculum

Root-knot nematode eggs were extracted from the heavily galled root of tomato. Tomato seedling was suspended in a conical flask containing the harvested nematodes; little quantity of distilled water was added to the content in the conical flask and kept close to the window for photosynthesis to continue. After 72 hours, it was observed that the population of the nematodes rapidly multiplied.

Estimation of Nematode Population

Nematode populations were estimated by counting the number of active juveniles in 1 ml of homogenized suspension of root-knot nematodes under a binocular research light microscope at x40 magnification. One milliliter of homogenized suspension contained an average of 22 nematode juveniles.

Preparation of Extract Concentration for *In Vitro* Evaluation

The *in vitro* nematicidal activity was laid in a Complete Randomized Design (CRD), conducted by preparing aqueous and ethanolic leaf extracts of *Azadirachta indica* (Neem) and *Senna alata* on the juveniles of root-knot nematodes (*Meloidogyne* spp.). One measuring one milliliter (1 ml) of 0.625, 1.25, 2.5 and 5 mg/ml concentrations of the plant extracts was added to 2 ml of a homogenized suspension containing 40 *Meloidogyne* spp. juveniles. Each treatment was replicated five times and maintained at room temperature. The mixtures were examined at intervals of 6 hours, 12 hours, 18 hours, and 24 hours to assess mortality rate. Mortality was determined by touching the juveniles with a fine needle to trigger movement, thus confirming whether they were dead or alive. The numbers of live and dead nematodes were counted and recorded as averages. A suspension of *Meloidogyne* spp. juveniles in distilled water was used as the control.

Experimental Site

The experiment was conducted in University of Jos, Jos

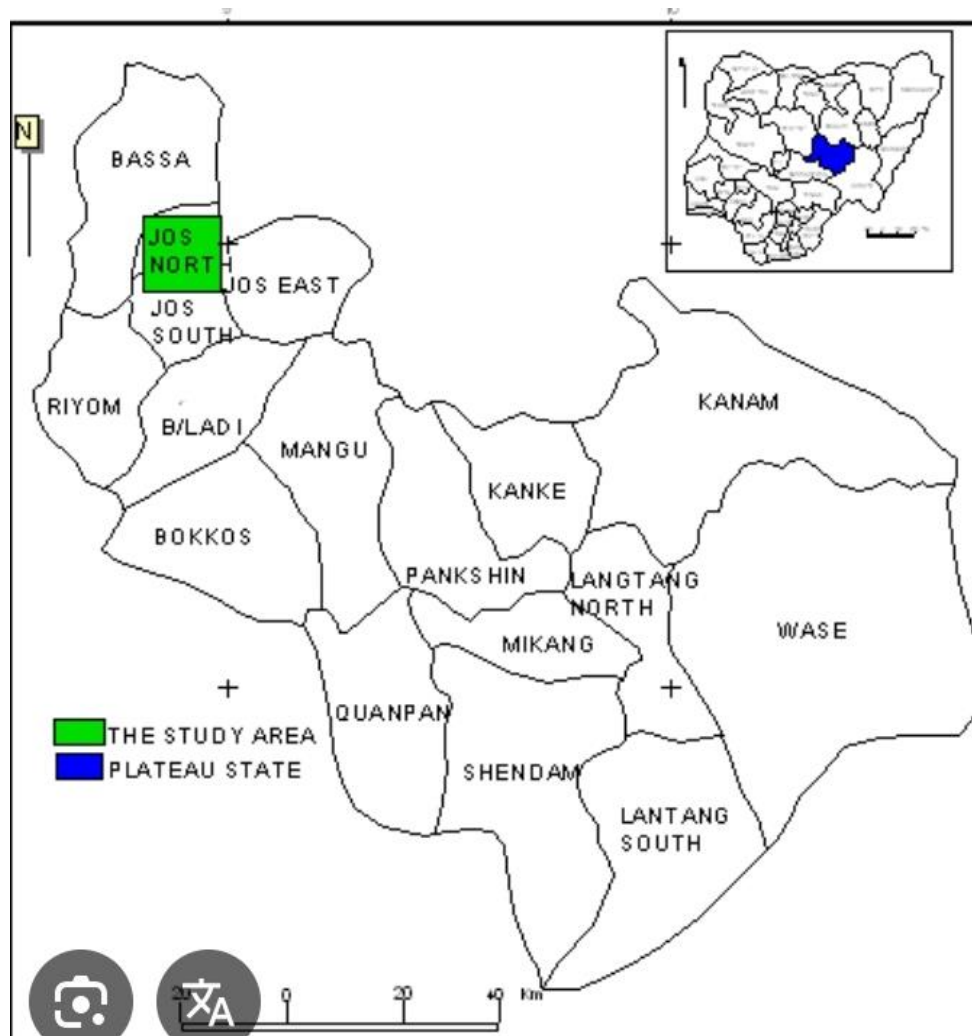


Figure 1: Map of Plateau State Showing the Study Area in green

North Local Government Area, Plateau State, Nigeria which lies within the Guinea Savannah ecological zone, between latitude $9^{\circ}52'N$ and longitude $8^{\circ}54'E$, at an elevation of about 1,200 m above sea level (Figure 1). The climate is characterized by a relatively cool temperature compared to other parts of Nigeria, with annual mean temperatures ranging from $18-25^{\circ}C$. Annual rainfall averages 1,200–1,400 mm, concentrated between May and October, while the dry season extends from November to April. Relative humidity fluctuates seasonally between 50–80% (Plateau State Ministry of Environment, 2020).

Planting Materials

The Roma tomato variety was employed for this experiment. The planting was done in polythene pots of 31cm in diameter and 42cm in height filled with top soil, mixed with sharp sand to the ratio of 3:1. The local

method of steam sterilization was adopted to substitute the use of autoclave machine or steam sterilizer. This was done by carefully heating the mixed soil in drums pot over-flame. The sterilized soil was amended with fertilizer.

Experimental Design

The experiment was laid in a randomized complete block design (RCBD) with twelve treatment combination in the order, two plant material (*Azadirachta indica* and *Senna alata*), two extraction solvents (aqueous and ethanolic), three concentrations (30 mg/ml, 45 mg/ml, and 60 mg/ml), a synthetic fungicide, Furadan (positive control), and a negative control (inoculated but untreated). Each treatment was replicated five times, resulting in a total of 60 experimental units (polythene bags). Tomato seeds were broadcasted on nursery bed and allowed to grow for four weeks (28 days). Healthy seedlings were

transplanted into 60 polythene bags (one seedling per bag). Each treatment was replicated five times. Three weeks after transplanting, the plants were inoculated with *Meloidogyne* spp. which involved pouring 16 ml of nematode suspension containing 2,000 juveniles into holes around the roots of each seedling. Two weeks after inoculation, the prepared extract concentrations (30 mg/ml, 45 mg/ml, and 60 mg/ml) were applied separately to the pots. Furadan (a standard nematicide), was applied at the rate of 4 kg/ha (equivalent to 7.7 mg/ml based on the surface area of the polythene bags) while untreated inoculated pots served as the negative control. The plants were maintained weed-free and harvested after 56 days. Agronomic parameters including shoot length, root length, root weight, number of root galls per plant, and number of fruits per plant were recorded before and at harvest. The number of galls per plant was counted

Data Analysis

Collected data were analyzed using the Statistical Package for Social Sciences (SPSS Statistics version 23). A two-way analysis of variance (ANOVA) was performed at 0.05 level of probability to determine significant differences among treatments. Means were separated using the Least Significant Difference (LSD) test.

RESULTS

Table 1 revealed the phytochemical constituents present in aqueous and ethanolic extracts of *A. indica* and *S. alata* including the presence of alkaloids, tannins, flavonoids, phenols, and steroids, while *A. indica* ethanolic extract was devoid of saponins, carbohydrates and anthraquinones. Again, Aqueous extracts had no cardiac glycosides. *Senna alata* had all the phytoconstituents assessed except terpenes which was absent in aqueous extracts of both plants (*A. indica* and *S. alata*).

Table 1: Phytochemical results of *A. indica* and *S. alata* leaf extracts.

| Constituents | <i>A. indica</i> | | <i>C. alata</i> | |
|-------------------|------------------|---------|-----------------|---------|
| | Aqueous | Ethanol | Aqueous | Ethanol |
| Alkaloids | + | + | + | + |
| Saponins | + | - | + | + |
| Tannins | + | + | + | + |
| Flavonoids | + | + | + | + |
| Carbohydrates | - | - | + | + |
| Phenols | + | + | + | + |
| Steroids | + | + | + | + |
| Anthraquinones | + | - | + | + |
| Cardiac glycoside | - | + | + | + |
| Terpenes | - | + | - | + |

Key: -=>absent + => present

Effect of Various Concentration of *A. Indica* Ethanolic Leaves Extract on Root-Knot Nematodes Second Juvenile Stage under Laboratory Conditions (*In Vitro*)

The effect of various concentrations of *A. indica* ethanolic leaf extract on root-knot nematode second-stage juveniles (J2) showed that at the lowest concentration (0.625 mg/ml), mortality was relatively low, starting at 8.33% after 6 hours and increasing gradually to 54.17% by 24 hours (Figure 2). A sharp increase in nematicidal activity was observed at 1.25 mg/ml, where mortality reached 41.67% at 6 hours and rose consistently to 95.83% at 24 hours. At 2.5 mg/ml, mortality was higher at all-time points, beginning at 58.33% at 6 hours, increasing to 91.67% at 18 hours, and reaching 100% at 24 hours. The strongest effect was recorded at 5 mg/ml, where mortality reached 72.92% within 6 hours, 83.33% at 12 hours, and complete mortality (100%) was achieved as early as 18 hours and sustained at 24 hours. In contrast, the control group exhibited negligible mortality, with a maximum of only 8.33% after 24 hours (Figure 2).

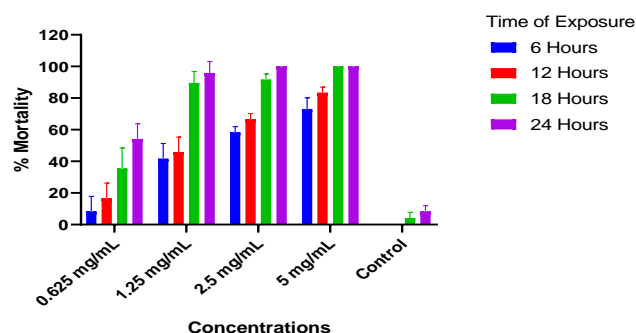


Figure 2: Effect of Various Concentration of *A. indica* Ethanolic Leaves Extract on Root-knot Nematodes Second Juvenile Stage under Laboratory Conditions

Effect of Various Concentration of *S. Alata* Ethanolic Leaves Extract on Root-Knot Nematodes Second Juvenile Stage under Laboratory Conditions

The effect of various concentrations of *S. alata* ethanolic leaf extract on root-knot nematode second-stage juveniles (J2) demonstrated that at the lowest concentration (0.625 mg/ml), mortality was relatively low at 16.67% after 6 hours but increased sharply to 72.08% at 12 hours, 87.50% at 18 hours (Figure 3), and complete mortality (100%) at 24 hours. At 1.25 mg/ml, mortality was slightly higher, starting at 27.08% after 6 hours, rising steadily to 77.92% at 12 hours and 87.50% at 18 hours, before reaching full mortality (100%) at 24 hours. A much stronger effect was observed at 2.5 mg/ml, where mortality reached 89.58% within 6 hours, increased to 97.92% by 12 hours, and achieved complete

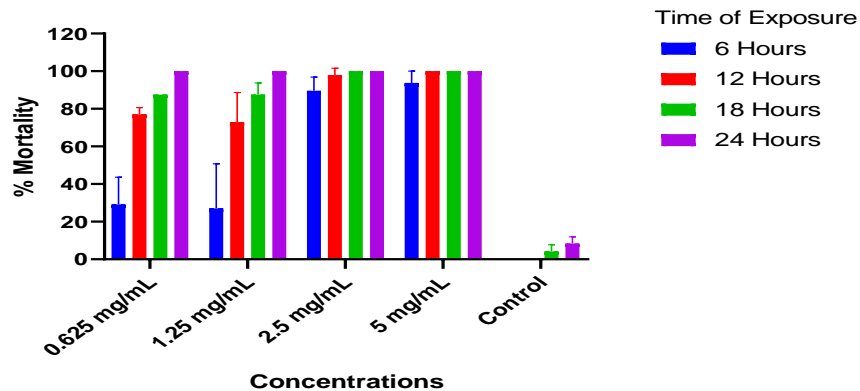


Figure 3: Effect of Various Concentration of *S. alata* Ethanol Leaves Extract on Root-knot Nematodes Second Juvenile Stage under Laboratory Conditions

Table 2: Effect of Various Concentration of *A. indica* Ethanol Leaves Extract on Root-knot Nematodes Second Juvenile Stage under Field Condition.

| Concentration (mg·ml ⁻¹) | Root gall index (0–5) | J2 / 250 cm ³ soil | Fruit yield (t·ha ⁻¹) | %CE (Gall index) |
|--------------------------------------|-----------------------|-------------------------------|-----------------------------------|------------------|
| Control (water) | 3.9 ± 0.2 | 1,250 ± 105 | 18.2 ± 1.1 | — |
| 0.625 | 3.0 ± 0.2 | 820 ± 95 | 21.0 ± 1.0 | 23.1% |
| 1.25 | 1.9 ± 0.2 | 420 ± 48 | 25.3 ± 1.2 | 51.3% |
| 2.5 | 1.0 ± 0.1 | 110 ± 18 | 29.1 ± 0.9 | 74.4% |
| 5.0 | 0.4 ± 0.05 | 18 ± 5 | 32.0 ± 0.7 | 89.7% |

Values = mean ± SEM; n = 4 plots; Gall index scored 0–5; J2 = juveniles per 250 cm³ soil; Eggs/root = total eggs recovered per root system; Yield in t·ha⁻¹. %CE = percent control efficacy relative to untreated control

nematode death by 18 hours, which was sustained through 24 hours. The highest concentration (5 mg/ml) produced the most rapid nematicidal effect, with 93.75% mortality at 6 hours and 100% mortality already achieved by 12 hours. In contrast, the control group showed minimal mortality throughout, with a maximum of only 8.33% at 24 hours (Figure 3).

Effect of Various Concentration of *A. Indica* Ethanol Leaves Extract on Root-Knot Nematodes Second Juvenile Stage under Field Condition

The results in (Table 2) showed that *A. indica* Ethanol leaf extract exerted a strong and concentration-dependent suppressive effect on root-knot nematodes under field conditions, with corresponding improvements in tomato yield. The untreated control plots exhibited the highest gall index (3.9 ± 0.2), the greatest number of juveniles (1,250 ± 105 J2/250 cm³ soil), and the lowest fruit yield (18.2 ± 1.1 t·ha⁻¹), reflecting severe nematode damage. Treatment with the lowest extract concentration (0.625 mg·ml⁻¹) moderately reduced the gall index to 3.0 ± 0.2 (23.1% control efficacy), decreased J2 counts to 820 ± 95, and enhanced yield to 21.0 ± 1.0 t·ha⁻¹. A stronger effect was observed at 1.25 mg·ml⁻¹, where gall index fell to 1.9 ± 0.2 (51.3% efficacy), nematode density decreased to 420 ± 48, and yield improved significantly to 25.3 ± 1.2 t·ha⁻¹. At 2.5 mg·ml⁻¹, the extract markedly suppressed nematode activity, lowering gall index to 1.0

± 0.1 (74.4% efficacy) and J2 counts to 110 ± 18, with a notable yield increase to 29.1 ± 0.9 t·ha⁻¹. The highest dose (5.0 mg·ml⁻¹) proved most effective, nearly eliminating root galls (0.4 ± 0.05; 89.7% efficacy), reducing J2 to only 18 ± 5, and producing the maximum yield (32.0 ± 0.7 t·ha⁻¹).

Effect of Various Concentrations of *C. Alata* Aqueous Leaf Extract on Root-Knot Nematodes (J2) Infestation of Tomato under Field Conditions

The results in (Table 3) demonstrates the nematicidal efficacy of *Senna alata* aqueous leaf extract against root-knot nematodes in tomato under field conditions, showing a clear dose-dependent trend in gall index reduction, juvenile suppression, and yield improvement. The untreated control recorded the highest gall index (3.8 ± 0.3), nematode density (1,210 ± 115 J2/250 cm³ soil), and lowest yield (18.0 ± 1.1 t·ha⁻¹), confirming severe nematode infestation. Application of 0.625 mg·ml⁻¹ extract produced a modest effect, lowering the gall index to 3.4 ± 0.2 (10.5% control efficacy), reducing J2 counts to 1,010 ± 95, and slightly increasing yield to 19.6 ± 0.8 t·ha⁻¹. At 1.25 mg·ml⁻¹, the extract showed stronger suppression, reducing gall index to 2.7 ± 0.2 (28.9% efficacy), J2 population to 730 ± 84, and enhancing yield to 21.9 ± 1.2 t·ha⁻¹. More pronounced effects were observed at 2.5 mg·ml⁻¹, with gall index declining to 1.9 ± 0.1 (50.0% efficacy), J2 counts decreasing to 350 ± 42,

Table 3: Effect of Various Concentrations of *S. alata* Aqueous Leaf Extract on Root-knot Nematodes (J2) Infestation of Tomato under Field Conditions.

| Concentration (mg·ml ⁻¹) | Root gall index (0–5) | J2 / 250 cm ³ soil | Fruit yield (t·ha ⁻¹) | %CE (Gall index) |
|--------------------------------------|-----------------------|-------------------------------|-----------------------------------|------------------|
| Control (water) | 3.8 ± 0.3 | 1,210 ± 115 | 18.0 ± 1.1 | — |
| 0.625 | 3.4 ± 0.2 | 1,010 ± 95 | 19.6 ± 0.8 | 10.5% |
| 1.25 | 2.7 ± 0.2 | 730 ± 84 | 21.9 ± 1.2 | 28.9% |
| 2.5 | 1.9 ± 0.1 | 350 ± 42 | 25.8 ± 1.0 | 50.0% |
| 5.0 | 1.0 ± 0.1 | 120 ± 18 | 29.5 ± 0.9 | 73.7% |

Values = mean ± SEM; n = 4 plots; Gall index scored 0–5; J2 = juveniles per 250 cm³ soil; Yield in t·ha⁻¹. %CE = percent control efficacy relative to untreated control.

Table 4: Effect of Various Concentrations of *S. alata* Ethanolic Leaf Extract on Root-knot Nematodes (J2) Infestation of Tomato under Field Conditions.

| Concentration (mg·ml ⁻¹) | Root gall index (0–5) | J2 / 250 cm ³ soil | Fruit yield (t·ha ⁻¹) | %CE (Gall index) |
|--------------------------------------|-----------------------|-------------------------------|-----------------------------------|------------------|
| Control (water) | 3.8 ± 0.3 | 1,210 ± 115 | 18.0 ± 1.1 | — |
| 0.625 | 3.1 ± 0.2 | 890 ± 88 | 20.3 ± 1.0 | 18.4% |
| 1.25 | 2.2 ± 0.2 | 480 ± 55 | 23.7 ± 1.1 | 42.1% |
| 2.5 | 1.3 ± 0.1 | 160 ± 24 | 27.8 ± 0.8 | 65.8% |
| 5.0 | 0.6 ± 0.05 | 30 ± 7 | 31.2 ± 0.7 | 84.2% |

Values = mean ± SEM; n = 4 plots; Gall index scored 0–5; J2 = juveniles per 250 cm³ soil; Yield in t·ha⁻¹. %CE = percent control efficacy relative to untreated control

and yield rising significantly to 25.8 ± 1.0 t·ha⁻¹. The highest concentration (5.0 mg·ml⁻¹) was most effective, nearly suppressing gall formation (1.0 ± 0.1; 73.7% efficacy), reducing J2 density to 120 ± 18, and producing the maximum yield (29.5 ± 0.9 t·ha⁻¹).

Effect of Various Concentrations of *C. Alata* Ethanolic Leaf Extract on Root-Knot Nematodes (J2) Infestation of Tomato under Field Conditions

The results in (Table 4) illustrates the effectiveness of *Cassia alata* ethanolic leaf extract in suppressing root-knot nematode infestation and enhancing tomato yield under field conditions, with results showing a strong concentration-dependent response. The untreated control had the highest gall index (3.8 ± 0.3), nematode density (1,210 ± 115 J2/250 cm³ soil), and lowest yield (18.0 ± 1.1 t·ha⁻¹), reflecting severe nematode damage. At the lowest extract concentration (0.625 mg·ml⁻¹), a moderate reduction in galling was observed (3.1 ± 0.2; 18.4% control efficacy), accompanied by a decrease in J2 density (890 ± 88) and a slight yield increase to 20.3 ± 1.0 t·ha⁻¹. The efficacy improved substantially at 1.25 mg·ml⁻¹, lowering gall index to 2.2 ± 0.2 (42.1% efficacy), reducing J2 population to 480 ± 55, and raising yield to 23.7 ± 1.1 t·ha⁻¹. At 2.5 mg·ml⁻¹, the nematocidal effect became more pronounced, with gall index dropping to 1.3 ± 0.1 (65.8% efficacy), J2 reduced to 160 ± 24, and yield markedly improved to 27.8 ± 0.8 t·ha⁻¹. The maximum concentration (5.0 mg·ml⁻¹) provided the strongest control, nearly eliminating gall formation (0.6 ± 0.05; 84.2% efficacy), suppressing J2 density to just 30 ± 7, and achieving the highest yield (31.2 ± 0.7 t·ha⁻¹).

DISCUSSION

The phytochemical screening of *A. indica* and *S. alata* leaves in this study showed a wide range of bioactive compounds, and the results are largely consistent with earlier findings reported by other researchers. The observed phytochemical composition aligns with recent findings that plant secondary metabolites such as alkaloids, flavonoids, and phenols contribute to nematocidal activity (Ezeonu et al., 2023). For *A. indica*, both aqueous and ethanolic extracts contained alkaloids, tannins, flavonoids, phenols, steroids, and cardiac glycosides, although the relative abundance varied with solvent type. This observation agrees with the work of Kumar et al. (2020), who reported that neem leaves generally possess alkaloids, flavonoids, tannins, saponins, terpenoids, and glycosides, though solvent polarity significantly influences the compounds detected. Similarly, Chukwu et al. (2022) found differences in the phytochemical composition of *A. indica* depending on the extraction solvent, supporting the variations observed in this study. In the case of *S. alata*, both aqueous and ethanolic extracts revealed alkaloids, tannins, flavonoids, phenols, saponins, steroids, and anthraquinones, which aligns with the findings of Akinmoladun et al. (2019), who also detected these classes of metabolites in *Senna alata* leaves, attributing differences in intensity to solvent efficiency. Ofori-Kwakye et al. (2020) further confirmed that *S. alata* is particularly rich in anthraquinones, tannins, and flavonoids, with qualitative differences depending on the extraction method used. The absence of certain compounds in some extracts, as recorded in this study, is also in line with earlier reports that solvent type, plant part, and environmental conditions often

determine the diversity and concentration of phytochemicals present.

Generally, this *in vitro* study demonstrated that both *A. indica* and *S. alata* leaf extracts exhibited significant nematicidal activity against root-knot nematode juveniles (J2), with their efficacy varying according to solvent type and concentration. These findings are consistent with previous studies that reported the nematicidal potential of neem extracts due to bioactive compounds such as azadirachtin, salannin, and nimbin, which interfere with nematode reproduction, feeding, and survival (Hassan *et al.*, 2020; Adegbite & Adesiyan, 2021). Similarly, Akhtar and Malik (2020) found that ethanolic neem extracts exhibited stronger activity than aqueous preparations, likely because organic solvents enhanced the extraction of lipophilic secondary metabolites with nematicidal properties. *A. indica* aqueous and ethanolic leaf extracts exhibit potency on *Meloidogyne* spp., with effectiveness influenced by concentration, exposure time, and extraction method. The presence of phytochemicals in both plants explains their effectiveness in suppressing nematode populations. The study revealed a clear dose-dependent response, where higher concentrations resulted in increased nematode mortality. This trend is consistent with findings by Sambo *et al.* (2024), who reported similar patterns in neem-based treatments. Ethanolic extracts generally showed higher efficacy than aqueous extracts, likely due to enhanced extraction of bioactive compounds. This supports the findings of Hussain *et al.* (2023). Interestingly, *Senna alata* demonstrated rapid nematicidal activity, in some cases outperforming neem in terms of speed of action. This suggests that *S. alata* could serve as a viable alternative botanical nematicide, especially in regions where it is readily available. Field results further confirmed the laboratory findings, showing significant reductions in galling and nematode population, alongside improved tomato yield. This highlights the practical applicability of these plant extracts in sustainable agriculture. Overall, the study reinforces the potential of botanical extracts as eco-friendly alternatives to synthetic nematicides and contributes valuable comparative data on two important plant species. More recent investigations into botanical nematicides, such as those by Sharf *et al.* (2025), confirmed substantial reductions in juvenile viability and egg hatching when treated with neem-based compounds, further supporting the high nematicidal activity displayed by the extracts at elevated concentrations and extended exposure times.

Conclusion

This study demonstrated that both *Azadirachta indica* and *Senna alata* leaf extract contains diverse phytochemicals, including alkaloids, tannins, flavonoids, phenols, steroids, and glycosides, which contributed to their biological

activities. The ethanolic and aqueous extracts of both plants exhibited strong, dose and time-dependent nematicidal effects against root-knot nematodes (*Meloidogyne* spp.), with higher concentrations leading to complete juvenile mortality and significant yield improvement in tomato. The results confirmed the influence of solvent type on extract potency, with *A. indica* showing stronger effects in ethanol and *S. alata* demonstrating consistent activity across solvents. These findings highlight the potential of both *A. indica* and *S. alata* as eco-friendly alternatives to synthetic nematicides, offering sustainable solutions for nematode management in agriculture.

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