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INVESTIGATING THE POTENTIAL USE OF PLANT-BASED COMPOUNDS AS ENVIRONMENTALLY FRIENDLY MANAGEMENT STRATEGIES FOR CONTROLLING ROOT KNOT NEMATODES IN CABBAGE CROPS

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ABSTRACT. Vegetables are infected by root knot nematodes, especially *Meloidogyne incognita*, which results in both quantitative and qualitative losses. This study's objective was to assess the effectiveness of plant extracts from *Senna alata* and *Tamarindus indica* in controlling cabbage-infecting root knot nematodes. The experiment was carried out to determine the effect of aqueous and powdered extracts of *T. indica* and *S. alata* on the control of root knot nematodes in two cabbage varieties. The test plants underwent phytochemical screening. Data were gathered on plant height, shoot weight, root weight, yield and soil nematode populations. All numerical data were subjected to analysis of variance using the GENSTAT statistical programme. Treating F1 Majesty and F1 Minotaur with powdered *T. indica* extract resulted in a significantly better ($p>0.05$) growth and yield (62.77 cm and 53.77 cm) than the other treatments. Significant variations were found between the shoot, root and yield weights of treated plants and their control counterparts. The positive control had the highest number of galled roots in both varieties (6.25 and 8.27). The treated plants performed much better than the control plants. The experiment also revealed some compounds, such as hexadecanoic, butyric and octadecadienoic acid. Based on this study's findings, it is advisable to make use of these botanicals (*T. indica* and *S. alata*) on root knot-infested farms, as they are cheap, available and eco-friendly alternatives to chemical nematicides, which are expensive and not environmentally friendly.

Keywords: infecting; phytochemical; screening; significant; varieties.

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INTRODUCTION

Cabbage (*Brassica oleracea* L. var. capitata) is an important leafy vegetable from the Cruciferae family. India ranks second (8,755,000 tonnes annually) to China (33,881,515 tonnes annually) in cabbage production (Khan and Khan, 2021). In India, West Bengal (29.55 million tonnes) was the leading vegetable-producing state, followed by Uttar Pradesh (27.70 million tonnes) in 2018–2019 (Jayan, 2020). According to Dong (2018), the majority of this vital vegetable is produced in northern Nigeria, specifically Plateau State. Plateau State has the greatest altitude of all states in Nigeria, resulting in some areas with extremely cold climates that promote the production of peculiar crops. Cabbage can be pickled, fermented (for meals like sauerkraut), steamed, stewed, sautéed, braised, or eaten raw. It contains high contents of vitamins C and K, with 44% and 72% of the daily intake per 100 g, respectively (Jonatan and Maira, 2021) and is also a rich source of vitamin B6, calcium and dietary fibre (Tse and Eslick, 2014).

Cabbage production in developing nations is affected by factors such as insufficient farm inputs, soil infertility, inadequate storage facilities, inefficient transportation networks, frequent pest infestations and disease outbreaks. Plant-parasitic nematodes (PPNs) are devasting soil-borne pathogens that severely reduce the growth and yield of agriculture crops. Of all PPNs, root-knot nematodes (*Meloidogyne* spp.) are the most harmful pests worldwide.

Root-knot nematodes are plant parasitic nematodes from the genus *Meloidogyne* (Aminu-taiwo and Fawole, 2017). *Meloidogyne incognita* symptoms on plant roots are striking because their feeding can cause enormous galls or "knots" to grow throughout affected plant root systems, thereby preventing regular nutrient and water uptake from the soil (Montarry *et al.*, 2020).

Several approaches have been used in the past to combat pests and pathogens, such as root-knot nematodes. The most effective method has been fumigant application, as reported by Yadav *et al.* (2020). The use of synthetic chemical pesticides leads to unforeseen problems at the time of their introduction, as pesticides are generally persistent in nature (Baba *et al.*, 2020). This can cause secondary explosions of other pests, necessitating further control efforts (McCoy, 2020). Thus, the use of plant extracts as botanical control becomes necessary because they are simple to use, readily available, effective and environmentally benign, as reported by Mekidani *et al.* (2021), who investigated leaf extracts of *Tamarindus indica* (L.) and *Citrus sinensis* (L.) Osbeck on *M. incognita*.

Providing a solution to the difficulties posed by plant parasitic nematodes and food insecurity and boosting revenue through improved cabbage productivity are regarded as priorities. As a result, the sensitivity of cabbage to root-knot nematodes as well as the botanical effect on two cabbage varieties must be investigated. There is then the need to exploit the use of these bio-nematicides, i.e. leaf extracts of *T. indica* and *Senna alata* (L) Roxb. against root-knot nematodes, i.e. *M. incognita* on cabbage plants. The use and acceptance of these bio-nematicides will be economical, less tedious and ecologically

friendly, making them viable alternatives to imported, costly and environmentally persistent nematicides. Therefore, the aim of this work was to determine the susceptibility of cabbage varieties to root-knot nematode *M. incognita* under screenhouse conditions and its management using leaf extracts of *T. indica* and *S. alata*.

MATERIALS AND METHODS

Experimental site

This experiment was carried out in the screenhouse of the Department of Crop Protection, University of Ilorin, Nigeria.

Soil pasteurisation

Sandy loam topsoil was collected from farmland surrounding the Department of Agronomy Pavilion, University of Ilorin. The soil collected was steam pasteurised in a drum at 90°C for 9 h following a method modified from Gautam and Goswami (2002). The steam-pasteurised soil was allowed to cool for 72 h. The pasteurised soil was then weighed, and 8.5 kg was placed into each of 48 perforated 10-litre plastic buckets with an 11 cm diameter. The buckets were placed on a raised platform to prevent reinfestation by other microbes and stored within a screenhouse for planting.

Collection and preparation of plant extracts

The plants examined against *Meloidogyne* spp. on cabbage were leaves of *T. indica* and *S. alata*, both of which were harvested in the morning along the riverside at Kulende, Ilorin, Kwara State, before sunrise, and their identities were confirmed by the Department of Plant Biology Herbarium, University of Ilorin. *Tamarindus indica* and *Senna*. *alata* leaves were air dried for 14 days at room temperature (25-27°C). The aqueous extracts of the test plants were prepared by soaking 1 kg of the ground test plants in 4 L of 90°C hot water for 24 h, as reported by Oyedunmade and Izuogu (2011), and ground leaf extracts were sieved using 2-mm mesh. In both cases, the suspension was sieved through muslin cloth, and the resulting aqueous extracts were collected in containers. This functioned as a stock solution. Phytochemical screening and gas chromatography were performed on 500 g of powdered leaf samples by the Department of Chemical Engineering at the University of Ilorin.

Effect of plant extracts on cabbage plants infected with *Meloidogyne incognita* in a screenhouse

A study was conducted in the Screenhouse of Crop Protection, University of Ilorin, to determine the effect of aqueous leaf extracts on two cabbage varieties (F1 Majesty and F1 Minotaur) purchased from Premier Seeds, Sango area Ilorin, Kwara State. Perforated 10-L plastic buckets with an 11-cm diameter were filled with 8.5 kg of pasteurised soil and placed on an elevated platform to prevent reinfestation by other microbes. This experiment used a 6×2 factorial design, with 4 botanical extracts, 2 controls and 2 cabbage seed varieties, and each was replicated 4 times, resulting in a total of 48 buckets. Two seeds were placed in each bucket and left to germinate. At 1 week after sowing, 3 holes were placed at the base of each plant with a glass rod for inoculum inclusion, and 40 buckets were inoculated

with 500 newly hatched *M. incognita* juveniles. At 3 days after inoculation, 32 infected plants were treated with aqueous and powdered leaf extracts of *T. indica* and *S. alata* at doses of 10 mL and 20 g, respectively and this was repeated 1 month later. The remaining 16 plants were positive (inoculated plants) and negative (non-inoculated plants) in the morning and evening. The botanical treatments for the control of root knot nematodes were as follows: Ta: *T. indica* aqueous, Tp: *T. indica* powder, Sa: *S. alata* aqueous, Sp: *S. alata* powder, C+ve: inoculated control, C-ve: control without inoculation and treatment, V_1: F_1 Majesty cabbage, and V_2: F_1 Minotaur cabbage.

Nematode population extraction and estimation

To determine the exact population of *M. incognita* in the soil after the completion of the experiment, nematodes were extracted and estimated using Baermann's funnel technique and Cobb's sieving and decanting methods, respectively. The final soil nematode number was calculated using the reproduction index formula, R=Pf/Pi, where Pf represents the final nematode population and Pi represents the initial nematode population.

Data collection

Data were collected on plant height, number of leaves, leaf breadth, head weight, soil nematode population 1 month after planting (initial nematode population), and final soil nematode populations at harvest (11–13 weeks). Root gall index was rated using the method of Bridge and Page (1980), as described below: 0 – no root knots; 1 – few small knots, difficult to find; 2 – small knots only, but clearly visible, main roots clean; 3 – Some larger knots visible, main root clean; 4 – large, knots predominant but main root clean; 5 – 50% of roots affected knotting on some main roots; 6 – knotting on main roots; 7 – majority of main roots knotted; 8 – all main roots, including tap roots, knotted, few clean roots visible; 9 – all roots severely knotted; 10 – all roots severely knotted, no root system, plant usually dead.

Data analysis

All numerical data collected were subjected to analysis of variance (ANOVA) using SPSS software, and significant means were separated using Duncan's multiple range test (DMRT) at alpha = 0.05.

RESULTS

GC-MS analysis of methanolic *T. indica* leaf extract

The methanolic *T. indica* leaf extract produced many peaks, each representing a different component, as illustrated in the chromatogram by gas chromatography-mass spectrometry (GC-MS). The identification of phytochemical compounds was based on the peak area, retention time and molecular formula (*Table 1*). The results revealed the presence and retention time of hexadecanoic acid, butyric acid and octadecadienoic acid. Butyric acid had the highest molecular weight (284.50) at a retention time of 38.59.

GC-MS analysis of the methanolic *S. alata* leaf extract

In this extract, 11 compounds, including Methylpentadecanoate, Hexadecanoic acid, and Methyloctadec, were identified by their retention times in the GC-MS analysis of methanolic *S.*

alata leaf extract and exhibited various phytochemical activities. Glycerol-1,3-dipalmitate recorded the highest molecular weight (568) at a retention time of 18.73.

Effects of treatments on plant height

Table 3 indicates the impact of plant extracts on the plant height in cabbage types affected by root knot nematodes.

There was a substantial ($p<0.05$) difference in the impact of plant extracts on plant height growth.

Cabbage treated with powdered *T. indica* extract had the highest plant height (26.38 and 28.38 cm), followed by aqueous *T. indica* extract (27.88 and 24.75 cm). Plants treated with aqueous *S. alata* extract showed a significantly higher plant height than plants treated with powdered *S. alata* extract (26.23 and 25.48 cm).

However, all treated cabbages were taller than the controls. The positive controls (inoculated cabbage) had the shortest plant height. F1 Minotaur outperformed F1 Majesty, with a plant height of 28.38 cm.

Table 1 – Bioactive constituents identified in methanolic extracts from *Tamarindus indica* leaves

Peak no.	Compound name	Molecular formula	Molecular weight (g/mol)	Retention Time (min)	Area (%)
1	Bicyclo[3.1.1]heptane, 2,6,6-trimethyl(1.alpha.,2.beta.,5.alpha.)	$C_{10}H_{18}$	138.25	36.257	3.01
2	n-Hexadecanoic acid	$C_{16}H_{32}O_2$	256.40	37.771	38.70
3	Butyric acid, 3-tetradecyl ester	$C_{18}H_{36}O_2$	284.50	38.590	1.77
4	9,12-Octadecadienoic acid (Z,Z)	$C_{18}H_{32}O_2$	280.40	38.884	56.52

Table 2 – Bioactive constituents identified in methanolic extracts from *Senna alata* leaves

Peak no.	Compound name	Molecular formula	Molecular weight (g/mol)	RT (min)	Area (%)
1	Methylpentadecanoate	$C_{16}H_{32}O_2$	256	15.41	0.47
2	n-Hexadecanoic acid	$C_{16}H_{32}O_2$	256	15.82	9.49
3	Methyloctadec-9-enoate	$C_{19}H_{36}O_2$	296	17.08	0.93
4	6-Octadecenoic acid	$C_{18}H_{34}O_2$	282	17.48	24.99
5	Octadecanoic acid	$C_{18}H_{34}O_2$	284	17.69	18.08
6	Glycerol-1,3-dipalmitate	$C_{35}H_{68}O_5$	568	18.73	2.99
7	9-Octadecenoyl chloride	$C_{18}H_{33}ClO$	300	19.79	1.19
8	9-Octadecenal	$C_{18}H_{34}O$	266	20.19	5.49
9	3-Hydroxypropyl-9-octadecanoate	$C_{21}H_{40}O_3$	340	20.68	3.64
10	4Dimethylsilyloxypentadecane	$C_{17}H_{38}OSi$	286	21.64	11.87
11	2,3-Dihydroxypropyl-9-octadecenoate	$C_{21}H_{40}O_4$	356	21.92	20.86

Effects of treatments on the number of leaves in two cabbage varieties

Table 4 shows the impact of plant extracts on the number of leaves in cabbage infected with root knot nematode. The effects of the plant extracts were not statistically different ($p>0.05$) in weeks 2 and 4. Plants treated with powdered *T. indica* extract recorded the highest number of leaves (14.75 and 16.00), followed by aqueous *T. indica* extract (12.75 and 13.00). Cabbage treated with powdered *S. alata* extract (13.75 and 14.50 leaves) outperformed that treated with aqueous *S. alata* extract (11.50 and 12.55 leaves). However, all treated cabbage recorded a higher number of leaves than the controls. Positive controls (inoculated cabbage) recorded the least leaves. Among the two cabbage varieties, F_1 Minotaur performed better than F1 Majesty, having a higher number of leaves (16.00).

Effect of treatment on the leaf breadth of cabbage

Table 5 shows the effects of plant extracts on the growth and breadth of leaves in two cabbage varieties infected with root knot nematode. The effects of the plant extracts on leaf breadth significantly differed ($p<0.05$). Plants treated with powdered *T. indica* extract recorded the highest leaf breadth (12.05 and 11.35 cm), followed by aqueous *T. indica* extract (11.28 and 11.00 cm). Cabbage treated with powdered *S. alata* extract had 10.60 and 10.28 cm leaf breadths and performed substantially better than the aqueous extract (8.98 and 9.60 cm). However, all treated cabbages recorded higher leaf breadths than the controls. The positive control (inoculated cabbage) recorded the lowest leaf breadth. Among the two cabbage varieties, F1 Majesty performed better than F_1 Minotaur, having a higher leaf breadth (12.05 cm).

Effect of treatment on cabbage yield

The effects of plant extracts on cabbage yield affected by root knot nematode are presented in *Table 6*. The effects of the plant extracts on the yield of both varieties significantly differed ($p<0.05$). Treating F1 Majesty and F1 Minotaur with powdered *T. indica* produced considerably higher yields of 76.37 and 65.67 g, respectively.

However, F_1 Majesty treated with powdered *T. indica* had a higher yield than F_1 Minotaur. Other treatments performed better than the controls. The inoculated control had the lowest yield for both varieties (30.17 and 26.87 g).

Effect of treatments on soil nematode population

The effect of plant extracts on the soil nematode population of cabbage infected by root knot nematodes is presented in *Table 7*. Soil treated with powdered *T. indica* had the fewest nematodes in a 250-mL soil suspension (8.00 and 2.00 at harvest), followed by soil treated with the aqueous *T. indica* extract, which contained 35.70 and 15.33 nematodes at harvest. Soil treated with aqueous and powdered extracts of *S. alata* performed better than the controls. Untreated soil recorded the highest number of soil nematodes, with 345.30 and 400.70 at 1 month after sowing and 408.00 and 425.00 at harvest. Infected F1 Majesty cabbage had fewer soil nematodes than infected F1 Minotaur cabbage at 1 month after sowing and harvest.

Table 3 – Effects of plant extracts on the plant height (cm) of two cabbage varieties infected with root knot nematode

TRT	2 WAS Var.		4 WAS Var.		6 WAS Var.		8 WAS Var.		10 WAS Var.	
	V_1	V_2	V_1	V_2	V_1	V_2	V_1	V_2	V_1	V_2
Ta	7.68^{a}	6.43^{d}	12.78^{a}	11.15^{d}	17.47^{ab}	15.73^{d}	24.00^{b}	20.73^{e}	27.88^{a}	24.75^{f}
Tp	6.40^{c}	6.90^{c}	9.70^{e}	11.13^{d}	14.87^{cd}	15.63^{d}	20.60^{e}	22.65^{b}	26.38^{b}	28.38^{a}
Sa	5.60^{e}	6.83^{c}	10.33^{c}	12.00^{b}	16.17^{bc}	16.70^{b}	22.03^{c}	22.28^{c}	26.23^{c}	25.48^{e}
Sp	5.90^{d}	7.13^{b}	10.05^{d}	11.40^{c}	14.05^{d}	16.05^{c}	20.03^{f}	20.83^{e}	24.15^{d}	25.63^{d}
C+ve	6.88^{b}	6.28^{e}	9.38^{f}	9.73^{e}	15.05^{cd}	14.50^{e}	21.90^{d}	21.75^{d}	22.68^{e}	21.83^{b}
C-ve	6.83^{b}	7.48^{a}	11.40^{b}	12.13^{a}	17.75^{a}	18.03^{a}	24.48^{a}	24.75^{a}	24.88^{c}	25.73^{c}
$LSD_{(0.05)}$	**0.12**	**0.11**	**0.09**	**0.11**	**1.49**	**0.10**	**0.12**	**0.34**	**0.08**	**0.07**

Means in the same column with the same superscript letter(s) are not significantly different using LSD at a 5% probability level. Keys: WAS = Weeks after sowing; TRT = Treatment; Ta = Aqueous *Tamarindus indica* extract; Tp = Powdered *T. indica* extract; Sa = Aqueous *Senna alata* extract; Sp = Powdered *S. alata* extract; C+ve = Inoculated control; C-ve = Control without inoculation or treatment; V_1 = F_1 Majesty; V_2 = F_1 Minotaur; LSD = Least significant difference

Table 4 – Effects of plant extracts on the number of leaves of two cabbage varieties infected with root knot nematode

TRT	2 WAS Var.		4 WAS Var.		6 WAS Var.		8 WAS Var.		10 WAS Var.	
	V_1	V_2	V_1	V_2	V_1	V_2	V_1	V_2	V_1	V_2
Ta	3.75^{a}	4.00^{a}	6.25^{a}	6.25^{a}	7.75^{b}	8.00^{ab}	10.25^{b}	10.00^{b}	12.75^{c}	13.50^{c}
Tp	3.80^{a}	4.75^{a}	6.75^{a}	6.75^{a}	7.50^{a}	8.25^{a}	10.75^{a}	11.50^{a}	14.75^{a}	16.00^{a}
Sa	3.40^{a}	4.00^{a}	6.15^{a}	6.75^{a}	7.00^{c}	7.25^{cd}	9.00^{c}	9.50^{bc}	11.50^{d}	12.55^{d}
Sp	3.75^{a}	4.00^{a}	6.05^{a}	6.50^{a}	5.65^{b}	6.75^{d}	8.00^{d}	9.00^{c}	13.75^{b}	14.00^{b}
C-ve	3.75^{a}	4.75^{a}	6.05^{a}	6.00^{a}	6.55^{b}	7.40^{bc}	7.75^{e}	7.00^{e}	9.25^{e}	10.50^{e}
C+ve	3.75^{a}	4.75^{a}	6.75^{a}	6.50^{a}	7.50^{c}	8.00^{ab}	8.00^{d}	8.25^{d}	11.00^{d}	12.10^{d}
$LSD_{(0.05)}$	**Ns**	**Ns**	**Ns**	**Ns**	**0.34**	**0.39**	**0.44**	**0.46**	**0.60**	**0.66**

Means in the same column with the same superscript letter(s) are not significantly different using LSD at a 5% probability level. Keys: WAS = Weeks after sowing; TRT = Treatment; Ta = Aqueous *Tamarindus indica* extract; Tp = Powdered *T. indica* extract; Sa = Aqueous *Senna alata* extract; Sp = Powdered *S. alata* extract; C+ve = Inoculated control; C-ve = Control without inoculation or treatment; V1 = F1 Majesty; V2 = F1 Minotaur; LSD = Least significant difference

Table 5 – Effects of plant extracts on the leaf breadth (cm) of two cabbage varieties infected with root knot nematode

TRT	2 WAS Var.		4 WAS Var.		6 WAS Var.		8 WAS Var.		10 WAS Var.	
	V_1	V_2	V_1	V_2	V_1	V_2	V_1	V_2	V_1	V_2
Ta	2.25^{a}	1.88^{c}	3.63^{c}	4.18^{a}	6.25^{c}	6.58^{a}	9.10^{c}	8.45^{a}	11.28^{b}	11.00^{b}
Tp	2.08^{b}	2.08^{b}	3.40^{d}	3.88^{b}	4.93^{f}	6.13^{b}	7.55^{e}	8.23^{a}	12.05^{a}	11.35^{a}
Sa	2.05^{bc}	2.33^{a}	3.63^{c}	3.60^{c}	5.90^{d}	4.68^{f}	8.73^{d}	7.95^{c}	8.98^{e}	9.60^{d}
Sp	2.00^{cd}	2.08^{b}	3.43^{d}	3.50^{d}	5.48^{e}	5.23^{d}	7.43^{f}	7.83^{d}	10.60^{d}	10.28^{c}
C+ve	2.03^{bcd}	2.00^{b}	4.10^{a}	3.15^{e}	7.50^{a}	5.00^{e}	9.00^{b}	7.15^{e}	9.00^{e}	10.15^{c}
C-ve	1.98^{d}	2.03^{b}	3.83^{b}	3.65^{c}	6.83^{b}	5.95^{c}	10.03^{a}	8.10^{b}	11.35^{b}	11.33^{a}
$LSD_{(0.05)}$	**0.07**	**0.09**	**0.08**	**0.09**	**0.09**	**0.09**	**0.09**	**0.08**	**0.12**	**0.09**

Means in the same column with the same superscript letter(s) are not significantly different using LSD at a 5% probability level. Keys: WAS = Weeks after sowing; TRT = Treatment; Ta = Aqueous *Tamarindus indica* extract; Tp = Powdered *T. indica* extract; Sa = Aqueous *Senna alata* extract; Sp = Powdered *S. alata* extract; C+ve = Inoculated control; C-ve = Control without inoculation or treatment; V1 = F1 Majesty; V2 = F1 Minotaur; LSD = Least significant difference

Effects of treatments on the gall index

Table 8 shows the galling index of cabbage plants as affected by the plant extracts.

There was a significant ($p<0.05$) difference in the number of galls found on the roots of both varieties. The positive control (inoculated cabbage) recorded the highest root gall rate compared with treated cabbage (6.25 and 8.25, respectively).

There were significant differences between the treated cabbages. Cabbage treated with powdered *T. indica* extract had the lowest root galling rate, followed by roots treated with aqueous *T. indica* extract. Cabbage roots treated with *S. alata* showed the most gall rooting with both aqueous and powdered extracts. F1 Majesty treated with plant extracts had much smaller root galls (0.75).

Table 6 – Effects of plant extracts on the yield (g) of two cabbage varieties infected with root knot nematode

TRT	V_1	V_2
Ta	62.77^{b}	53.77^{b}
Tp	76.37^{a}	65.67^{a}
Sa	52.30^{c}	50.37^{b}
Sp	62.07^{b}	50.53^{b}
C+ve	30.17^{e}	26.87^{d}
C-ve	40.40^{d}	35.63^{c}
$LSD_{(0.05)}$	**7.39**	**6.35**

Means in the same column with the same superscript letter(s) are not significantly different using LSD at a 5% probability level. Keys: WAS = Weeks after sowing; TRT = Treatment; Ta = Aqueous *Tamarindus indica* extract; Tp = Powdered *T. indica* extract; Sa = Aqueous *Senna alata* extract; Sp = Powdered *S. alata* extract; C+ve = Inoculated control; C-ve = Control without inoculation or treatment; V1 = F1 Majesty; V2 = F1 Minotaur; LSD = Least significant difference

Table 7 – Effects of plant extracts on the soil population of two cabbage varieties infected with root knot nematode

TRT	F_1 Majesty	F_1 Minotaur
Ta	2.00^{b}	1.25^{c}
Tp	0.75^{a}	0.86^{a}
Sa	2.25^{b}	6.25^{c}
Sp	5.75^{c}	1.75^{b}
C+ve	6.25^{d}	8.25^{d}
$LSD_{(0.05)}$	**0.66**	**0.79**

Means in the same column with the same superscript letter(s) are not significantly different using LSD at a 5% probability level. Keys: WAS = Weeks after sowing; TRT = Treatment; Ta = Aqueous *Tamarindus indica* extract; Tp = Powdered *T. indica* extract; Sa = Aqueous *Senna alata* extract; Sp = Powdered *S. alata* extract; C+ve = Inoculated control; C-ve = Control without inoculation or treatment; V1 = F1 Majesty; V2 = F1 Minotaur; LSD = Least significant difference

Table 8 – Effects of plant extracts on the gall index of two cabbage varieties infected with root knot nematode

TRT	F_1 Majesty	F_1 Minotaur
Ta	2.00^{b}	1.25^{c}
Tp	0.75^{a}	0.86^{a}
Sa	2.25^{b}	6.25^{c}
Sp	5.75^{c}	1.75^{b}
C+ve	6.25^{d}	8.25^{d}
$LSD_{(0.05)}$	**0.66**	**0.79**

Means in the same column with the same superscript letter(s) are not significantly different using LSD at a 5% probability level. Keys: WAS = Weeks after sowing; TRT = Treatment; Ta = Aqueous *Tamarindus indica* extract; Tp = Powdered *T. indica* extract; Sa = Aqueous *Senna alata* extract; Sp = Powdered *S. alata* extract; C+ve = Inoculated control; C-ve = Control without inoculation or treatment; V1 = F1 Majesty; V2 = F1 Minotaur; LSD = Least significant difference

Cabbage root response to *Meloidogyne incognita* and botanicals

Figure 1 and *Figure 2* compare the response of cabbage roots to root knot nematodes and botanical treatments. *Figure 1* shows galled cabbage roots infected with root knot nematodes without botanical application and *Figure*

2 displays clean cabbage roots inoculated with *M. incognita* and treated with botanicals.

Figure 1 – Cabbage roots inoculated with *Meloidogyne incognita*

DISCUSSION

The results demonstrated that root knot nematodes significantly decreased the height, number of leaves and yield of cabbage plants grown in nematode-infested soil, which exhibited retarded growth compared to their control counterparts. The treatment extracts (*T. indica* and *S. alata*) significantly improved cabbage growth and yield and reduced the soil and root nematodes. The effect of the botanicals might be due to the presence of organic acid compounds, such as butyric, hexadecanoic and octadecanoic acid. These findings are consistent with previous studies, such as Mekidani *et al.* (2021), who investigated the effect of *T. indica* and *C. sinensis* leaf and peel extracts to control root knot nematode.

Figure 2 – Cabbage roots treated with botanical extracts

Danahap *et al.* (2024) reported the effect of aqueous *Azadirachta indica* (A. Juss) extract on *Meloidogyne* species (root knot nematodes) mortality, and Udo *et al.* (2020) reported the use of *S. alata* leaf extract in the management of root knot disease in okra. Moosavi (2012) observed the efficacy of herbal powders and their aqeous extracts against *Meloidogyne javanica*. Among the treatment extracts, the powdered *T. indica* extract had the greatest influence on cabbage growth and yield, followed by the aqueous *T. indica* extract. Both aqueous and powdered *S. alata* extracts performed better than the controls in terms of growth and yield. Inoculated control cabbage (+ve) had a high level of susceptibility to root knot nematode, as evidenced by its heavily galled roots. This was followed by cabbage treated with *S. alata*, which showed a moderate level of susceptibility with few root galls. Non-inoculated (-ve) controls had clean

roots. Generally, all cabbage treated with botanicals performed significantly better than their control counterparts, showing increased growth and yield and reduced galling rates. The plant extracts were successful because they contained organic acids, such as butyric and hexacadonic acid, which may have been responsible for stopping nematodes from feeding, migrating, enabling cell development and reproduction, and inflicting plant harm. The significant performance of *T. indica* on growth and yield and its effect on soil and root nematodes might be due to the presence of butyric acid, which was present in the extracts. Butyric acid supports plant development with a high yield and has been used to control parasitic microorganisms (Šípošová *et al.*, 2021). Therefore, the use of botanicals in the management of plant parasitic nematodes has been widely viewed as one of the most practical alternatives to synthetic pesticides, especially in developing nations because botanicals are cheaper, cost-effective, readily available and can be easily adopted by local farmers (Ngegba *et al.*, 2022).

The two varieties responded well to the pathogen; however, variety F1 Majesty performed significantly better than F1 Minotaur in growth, yield and nematode reduction. F1 Majesty's success with the treatments could be attributed to some inherent genetic characteristics. It is also likely that changes in soil physical and chemical conditions caused by soil amendment in the trials affected the plant–nematode connections, making the plant's roots more resistant to nematode development.

GC-MS identified the following compounds in *T. indica* extracts: Bicyclo[3.1.1]heptane, 2,6,6-trimethyl(1.alpha.,2.beta.,5.alpha.), n-Hexadecanoic acid, Butyric acid, 3-tetradecyl ester and 9,12-Octadecadienoic acid (Z,Z). *Senna alata* extracts contained Methylpentadecanoate, n-Hexadecanoic acid, Methyloctadec-9-enoate, 6-Octadecenoic acid, Octadecanoic acid, Glycerol-1,3-dipalmitate, 9-Octadecenoyl chloride, 9-Octadecenal, 3-Hydroxypropyl-9-octadecanoate, 4Dimethylsilyloxypentadecane and 2,3-Dihydroxypropyl-9-octadecenoate. Some of these organic acids affect soil microorganisms, support plant development and increase yield. Adekanmi *et al.* (2022) reported that butyric acid increased the concentration of some mineral nutrients, such as N, K, Ca, S and Z, in the soil.

CONCLUSIONS

This research suggests that *T. indica* and *S. alata* extracts can be utilised in the control of root knot nematodes and may have potential as biopesticides for the control of nematodes, as they displayed nematicidal properties. F_1 Majesty performed better than F_1 Minotaur because it displayed clean roots (no galls) at harvest. More research might help to determine an appropriate concentration of the botanical extract to be applied to soils highly infested with *M. incognita*.

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