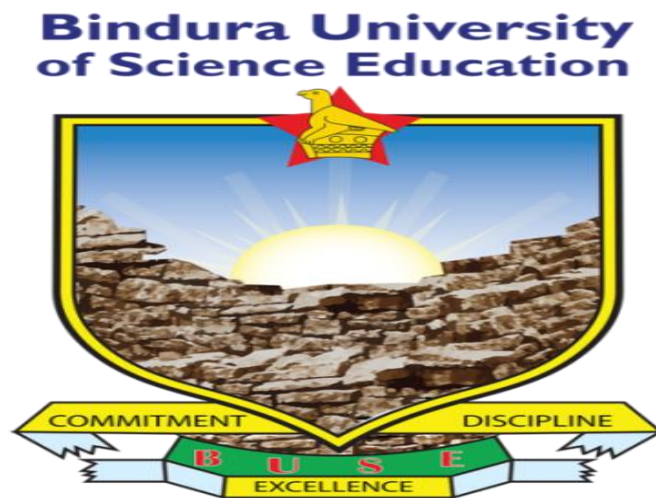


BINDURA UNIVERSITY OF SCIENCE EDUCATION
FACULTY OF AGRICULTURE & ENVIRONMENTAL SCIENCE
DEPARTMENT OF CROP SCIENCE
DAMAGE EFFECTS OF ROOT KNOT NEMATODES (*MELODIOGYN*
JAVANICA) ON CHIA (*SALVIA HISPANICA*)



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B225027B

***A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS OF THE BACHELOR OF SCIENCE HONOURS DEGREE IN
AGRICULTURE (CROP SCIENCE)***

Supervisor: Dr N Mgocheki

June 2026

DECLARATION

I, Denhere Amos, do hereby declare that this research project is a result of my original research work undertaken by myself except where clearly and specifically acknowledged. It is being submitted for the fulfilment of the Bachelor of Agricultural Science Honours Degree (Crop Science). It has not been submitted before for any degree or examination at any other University.

Name: Denhere Amos

I have supervised the research project for the above-mentioned student and I am convinced that the research project can be submitted for marking.

Project Supervisors:

i) NMgocheki__Signature ` ` ` _Date: 21 June 2026

ii) _____ Signature_____Date:

I certify that I have checked the Research project and I am satisfied that it conforms to the Department of Crop Science guidelines for project preparation and presentation. I therefore authorize the student to submit this dissertation for marking.

Chairperso _Mutsengi_Signature



Date: 26/08/2026

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Finally, my heartfelt appreciation goes to my loving parents and siblings who constantly encouraged and supported me financially in my studies despite economic hardships which the family was facing during my period of study.

DEDICATION

To my lovely parents, Mr. and Mrs. Denhere.

ABSTRACT

Tobacco (*Nicotiana tabacum*), a key cash crop in Zimbabwe, is highly susceptible to root knot nematode infestations leading to huge yield losses. Traditionally, nematodes are controlled by crop rotation with grass fallows, meaning reduced income for farmers in those seasons when the land is fallow. The aim of this research was to determine the capacity of one chia variety (Jalisco) to suppress the root knot nematode (*Meloidogyne javanica*) populations when incorporated in tobacco rotations. An experiment was carried out at the Tobacco Research Board (Kutsaga) in the 2025 - 2026 rainy season. It was arranged in a Completely Randomized Design (CRD) with six treatments replicated five times. The treatments were based on *Meloidogyne javanica* inoculum concentrations applied to plants as follows: untreated control, 5000, 10000, 15000, 20000 and 25000 eggs per plant. The chia was planted in a greenhouse, inoculated with nematodes and observed for reaction over 10 weeks. The results demonstrated that, *Meloidogyne javanica* infection caused no significant effect ($p > 0.05$) on plant height and stalk dry weight in the early stages of growth that was at 4 weeks after inoculation for plant height and at 6 and 8 weeks after inoculation for stalk dry weight. Significant reduction in plant height and stalk dry weight were observed at 6, 8 and 10 weeks after inoculation for plant height and at 10 weeks after inoculation for stalk dry weight. Minimal nematode root galling damage scores ranging from 0 to 2 on a scale of 0 to 8 were observed across all the rates of inoculation. The weight of seeds produced per plant were not significantly different ($p > 0.05$) between the treatments. Based on the results of this trial, it is recommended that farmers incorporate chia into tobacco rotation cycles to keep *Meloidogyne javanica* populations low.

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LIST OF ACRONYMS AND ABBREVIAT

ANOVA:	Analysis of Variance
CRD:	Completely Randomized Design
FAO:	Food and Agriculture Organization
IPM:	Integrated Pest Management
LSD:	Least Significant Difference
Rep:	Replication
RKN:	Root Knot Nematode
spp:	Species
TIMB:	Tobacco Industry Marketing Board
TRB:	Tobacco Research Board
WAI:	Weeks After Inoculation

CHAPTER 1

1.0 Introduction

1.1 Background information

Salvia hispanica L commonly known as chia, is a small seeded (1-2 mm) annual herb originated from highlands of Mexico and Guatemala. Chia nutritionally rich, containing appreciable concentrations of omega-3 fatty acids, dietary fibre and plant-based proteins (Ullah *et al.*, 2020, Grancieri *et al.*, 2022). High nutritional content has elevated chia to the status of a functional food, making it a sought-after ingredient across a wide range of culinary applications globally (Nyingi & Mburu, 2021). Known also as Salba chia or Mexican chia, the seeds are recognised for both their dietary contributions and their traditional medicinal applications in some communities (Aguilar-Toala, 2022, Ozon, 2022).

Chia plant performs well under mild, relatively stable temperatures and performs poorly in waterlogged soils (FAO, 2023). In Zimbabwe, the recommended planting window falls between May and September, a cool dry period with temperatures of roughly 15 to 25 degrees Celsius, which aligns well with the crop's growth requirements. Growing chia during the wet season increase the risk of root rot and associated soil-borne diseases. Due to the declining profits in some traditional crops, Zimbabwean commercial farmers have increasingly turned to chia as a profitable alternative crop. Many have attended training sessions organised by the Foundation for Farmers and Chia Growers Zimbabwe to build technical capacity in high yield production. One Mt Hampden producer, Robert Hoy, noted that chia has demonstrated considerably stronger returns than some traditional cash crops such as tobacco and cotton (FAO, 2023, African Development Bank, 2024). This growing interest shows a broader shift toward more diversified cropping systems.

Crop production across Zimbabwe faces high pressure from pests and diseases, a situation exacerbated by climate change and widespread monoculture farming. Sikora (2021) noted that plant-parasitic nematodes, weeds and fungal pathogens have the potential to cause substantial losses in both crop quality and yield. Globally, economic damage attributable to plant-parasitic nematodes is conservatively estimated at US\$125 billion per annum (Coyne, 2022). Among these, *Meloidogyne* species are the most economically damaging and responsible for yield losses of between 15 and 28% (Rutter *et al.*, 2022, Coyne *et al.*, 2022). Historically, root knot nematode (RKN) management in Zimbabwe depended heavily on

fumigant nematicides such as methyl bromide and ethylene dibromide (Desaeger *et al.*, 2020, IITA, 2022). Although effective, these chemicals raise serious environmental concerns regarding their persistence in soil and harm to non-target organisms. Accordingly, integrated pest management (IPM) has been advocated as the preferred ecologically sound approach (CGIAR, 2022, Coyne *et al.*, 2022).

Crop rotation is widely recognised for its ability to help maintain soil health and interrupt the accumulation of pest populations over successive seasons (UNEP, 2023). In Zimbabwe, however, adoption of rotation systems among smallholder farmers remains low, as most continue to grow the same crop continuously while it remains economically rewarding (IFAD, 2023). Limited availability of alternative high-value crops suitable for rotation result in mono-cropping. Chia represents a compelling opportunity if proven resistant or tolerant to root knot nematodes, it could serve simultaneously as a nematode-suppressive rotation partner and a new income source for Zimbabwean farmers.

1.2 Problem Statement

Smallholder farmers dominate Zimbabwe's agricultural landscape and largely practise monoculture cropping systems (Mashingaidze, 2021). Continuous monocropping facilitates the progressive accumulation of nematode populations in the soil reducing yield quality and quantity while increasing production costs through increased nematode control expenditure (Mashingaidze *et al.*, 2021, IFAD, 2023). The main driver of this monoculture practice is the shortage of alternative high value crops that can be confidently incorporated into rotation systems. Consequently, nematode populations continue to build from one season to the next season, creating a cycle of crop loss and rising input costs that is difficult to break without viable rotation options.

1.3 Justification of the Study

Introducing chia (Jalisco) into rotation cycles with tobacco offers a potentially viable, non-chemical strategy for keeping root knot nematode populations below economically damaging thresholds. Effective nematode suppression directly improves tobacco quality and yield, shifting into better income for farmers. Chia can simultaneously provide an additional revenue stream making it an attractive dual purpose crop for Zimbabwean farmers seeking improved productivity and income stability without increased reliance on synthetic chemical inputs.

1.4 Aim

The aim of the study is to determine the capacity of chia in suppressing the root knot nematode (*Meloidogyne javanica*) populations.

1.5 Objectives

1. To determine the effects of *Meloidogyne javanica* infection on growth performance of chia.
2. To determine the root galling damage scores of *M. javanica* in chia.

1.6 Research Questions

What are the effects of *M. javanica* infection on the growth performance of chia?

What root galling damage scores does *M. javanica* produce in chia under varying inoculum concentrations?

1.7 Hypotheses

H_0 *Meloidogyne javanica* has no significant effect on growth performance nor cause root galling damage effect in chia.

H_1 *Meloidogyne javanica* has significant effect on growth performance of chia and can cause root galling damage effect in chia.

1.8 Limitations

The hatch rate of the eggs used as inoculum may have been lower than expected, potentially affecting inoculum viability.

Results obtained under glasshouse conditions may not be fully representative of open-field crop performance.

1.9 Delimitations

The study used a single chia variety (Jalisco) and a single nematode species (*M. javanica*).

Six inoculum levels were tested: 0, 5 000, 10 000, 15 000, 20 000 and 25 000 eggs per plant.

Four response variables were measured: plant height, stalk dry weight, root galling score (0-8 scale) and seed weight per plant.

The trial was conducted at a single site over one growing season.

1.10 Significance of the Study

This experiment provides practical insights into nematode management through chia and tobacco rotation, with the potential to reduce dependence on chemical (nematicides) while simultaneously supporting farmer income diversification.

CHAPTER 2

2.0 Literature Review

2.1 Agriculture in Zimbabwe

Agriculture is one of the most important sectors that support most Zimbabwe's economy, supporting the livelihoods of approximately 70% of the national population and contributing meaningfully to GDP (World Bank, 2024, FAO, 2023, African Development Bank, 2024). The sector underwent significant structural transformation following the Fast Track Land Reform Programme of 2000, which redistributed large scale commercial farms and redistributed in the dominance of smallholder agriculture (Chimbishi, 2022). This shift created food security challenges in certain contexts, it has also opened space for the farmers to grow different crops and farming systems suited to smallholder conditions.

2.2 Production of Chia in Zimbabwe

Chia is becoming an important oilseed crop in Zimbabwe's agricultural diversification drive, drawing interest from both commercial and smallholder producers due to strong international demand and adaptability to semi-arid growing conditions (Biswas *et al.*, 2023). Several companies and contract farming arrangements have started supporting smallholder chia cultivation, primarily targeting export markets. This trend aligns with Zimbabwe's broader policy objective of expanding its range of commercially viable non-traditional crops.

2.3 Chia Crop

Scientifically designated *Salvia hispanica* L, chia belongs to the Lamiaceae (mint) family and traces its origins to central Mexico and Guatemala, where it constituted a key component of the diets of ancient Aztec and Mayan civilisations (Motyka *et al.*, 2022). The crop is now cultivated across many regions globally owing to its nutritious seed composition and broad climatic adaptability. Morphologically, chia is an annual herbaceous plant reaching 0.8 to 1.5 metres in height. It produces opposite, serrated leaves of approximately 4-8 cm in length, with square-shaped stems characteristic of the mint family and blue, purple or white flowers arranged in clustered spikes. The seeds are tiny, oval shaped and may be black, brown, grey or white. Seed colour in chia is predominantly black or dark brown. Upon contact with water, they develop a gel-like mucilage from their soluble fibre content. The seed is the most

commercially valuable plant part owing to its high concentrations of omega-3 fatty acids, protein, fibre, antioxidants and essential minerals (Biswas *et al.*, 2023).

2.4 Uses of Chia

Chia seeds are widely and commonly used in the food industry, featuring in breakfast cereals, smoothies, beverages and baked goods. Regular consumption of chia is associated with improved cardiovascular function, weight management and enhanced glycaemic control that is from a health perspective (Biswas *et al.*, 2023). Chia oil is valued in both food processing and cosmetics owing to its high omega-3 content and oxidative stability (Huang *et al.*, 2025).

2.5 Chia Diseases

Although chia is generally hard, it is susceptible to a range of diseases including damping-off, powdery mildew, root rot, leaf spots, and root knot nematode infections (Motyka *et al.*, 2022). Disease problems tends to increase under excessive moisture, poor drainage or high-density planting underscoring the importance of appropriate agronomic management.

2.6 Root-Knot Nematodes

Meloidogyne spp, commonly known as root knot nematodes are microscopic sedentary obligate endoparasites that derive nourishment exclusively from living plant tissues (Khan *et al.*, 2023, Mourya *et al.*, 2023). They are among the most economically damaging pests of tobacco worldwide responsible for yield losses estimated at 15 to 28% (Shew and Lucas, 1991, Diaz-Silveira and Herrera, 1998). Over 90 *Meloidogyne* species have been documented as crop pathogens (Bhat *et al.*, 2023), with *M. javanica*, *M. hapla*, *M. incognita* and *M. arenaria* together accounting for approximately 95% of all infections (Walia & Khan, 2023; Khan *et al.*, 2023). Annual economic losses from plant-parasitic nematodes globally are estimated at US\$125 billion (FAO, 2024), with over 2 000 plant species recorded as susceptible hosts (Khan, 2023, Walia & Khan, 2023).

Another problem to concern is that root knot nematodes often make plants more vulnerable to other diseases, as root wounds created during feeding provide entry points for other pathogens (FAO, 2023). These combined infections produce disease complexes of considerable economic importance including bacterial wilt caused by the combined action of

M. javanica and *Ralstonia solanacearum*, root rot from *M. incognita* plus *Rhizoctonia solani* and vascular wilt from *M. javanica* combined with *Fusarium oxysporum* (Khan *et al.*, 2023).

2.7 Host Range

Root knot nematodes attack an extraordinarily broad array of plant hosts spanning vegetables, field crops, weeds, perennial ornamentals and plantation species (Walia & Khan, 2023, FAO, 2023). Important host crops include tomato, pepper, eggplant, Irish potato, carrot, cabbage, sugarcane, banana, sweet potato, pineapple, spinach and tobacco (Mourya & Khan, 2023).

2.8 Symptoms of Root-Knot Nematode Attack

Root knot nematode damage manifests through both belowground and aboveground symptoms. The most characteristic underground sign is the formation of root galls - irregular swellings that distort normal root architecture. Above ground, infected plants typically exhibit stunted growth, chlorosis, wilting and in severe cases premature senescence and plant death (Khan, 2023). Severe root morphology damage under intense nematode pressure impairs the plant's capacity to absorb water and nutrients compounding the physiological impact of infection.

2.9 Biology of Root-Knot Nematodes

The root knot nematode life cycle encompasses three broad stages egg, juvenile and adult. Development occurs primarily in the soil and within plant roots with a complete cycle taking approximately 21 to 28 days at a mean temperature of 30 degrees Celsius (Khan, 2023; Mourya, 2023). Females deposit eggs within root tissue, on the root surface or in surrounding soil, with each female capable of producing 500 to 1 500 eggs per cycle depending on environmental conditions. Through embryogenesis, eggs hatch into first-stage juveniles (J1), which then moult successively through four instars (J2 to J4) before reaching adulthood.

The second stage juvenile (J2) represents the most infective and damaging life stage being entirely dependent on the host plant for nutrients. Using its stylet, the J2 penetrates plant roots often at points of mechanical weakness such as wounds or newly emerging lateral roots and secretes enzymes that break down pectin and cellulose in cell walls to facilitate entry (Khan *et al.*, 2023). Once inside the root, the nematode migrates through cortical tissue to

establish a permanent feeding site chemically manipulating host cells to form characteristic giant cells that serve as a nutrient source for the remainder of its sedentary life (Bhat, 2024). Severe root vasculature damage can prevent the plant from drawing adequate water for photosynthesis, reducing the root system to little more than a shelter for the parasite, a state that can ultimately lead to complete crop failure.

2.10 Management of Root-Knot Nematodes in Zimbabwe

The most prevalent root knot nematode species affecting tobacco in Zimbabwe are *Meloidogyne javanica* and *Meloidogyne incognita*. Earlier management depended on fumigant nematicides including methyl bromide and ethylene dibromide (Khan *et al.*, 2023). Current chemical tools include methyl iodide (Karavina & Mandumbu, 2012), abamectin (Bhat *et al.*, 2023) and metham sodium (FAO, 2024). These chemical products raise legitimate sustainability concerns regarding their adverse impacts on soil ecology and non-target organisms (Bhat *et al.*, 2023). Integrated Pest Management, integrating biological, cultural and chemical tools to reduce nematode populations while minimising environmental impact (Khan, 2023). IPM is now recommended as preferred control approach.

2.11 Crop Rotation as a Nematode Control Method

Rotation helps to reduce the seasonal build-up of pest populations, including nematodes and contribute to overall soil health maintenance. Growing non host or tolerant crops into tobacco rotations is among the most established non chemical nematode management approaches. Adoption of rotation systems by smallholder farmers has historically been constrained by the perceived relative economic value of rotation crops and the practical challenges of longer timeframes and larger land areas that effective rotations require (FAO, 2024). Chia is a strong rotation candidate, particularly given its commercial value and potential nematode-suppressive properties. Demonstrating these properties would address both the economic and agronomic dimensions of rotation adoption among smallholder farmers.

CHAPTER 3

3.0 Materials and Methods

3.1 Study site

The experiment was carried out during the 2025-2026 rainy season at Kutsaga Research Station (Tobacco Research Board), situated approximately 15 km east of Harare's central business district (17.8294 degrees S, 31.047 degrees E). The station is found in agro-ecological Region IIa, characterised by a subtropical climate with annual rainfall of 800 to 1 000 mm and mean temperatures of 18 degrees Celsius in winter and 30 degrees Celsius in summer (Khan *et al.*, 2023). Soils at the site belong to Order III of the Zimbabwean soil classification, specifically Group 6 kaolitic sandy soils derived from granite parent material (Nyamapfene, 1991). The soils are deep and well-drained, with a measured pH of 5.2 conditions that are historically well-suited to tobacco cultivation.

3.2 Experimental Design

The experiment was arranged in a Completely Randomized Design (CRD) with six treatments each replicated five times giving a total of 30 experimental units. Treatments corresponded to six levels of *Meloidogyne javanica* inoculum: an uninoculated control (0 eggs) and concentrations of 5 000 (the standard rate used by TRB in tobacco and tomato trials), 10 000, 15 000, 20 000 and 25 000 eggs per plant. A single chia variety was used throughout the trial.

3.3 Land Preparation

Greenhouse soil was sourced from Kutsaga farm and prepared for fumigation ahead of sowing. Planting tables, the greenhouse floor and 15 cm diameter planting pots were sanitised using a 5% sodium hypochlorite solution five days before sowing to allow adequate drying prior to trial establishment.

3.4 Fumigation and Sowing

To eliminate any pre-existing nematode populations in the growing medium greenhouse soil was drenched with metham sodium (Herbifume) 28 days before sowing at a rate of 250 ml per

4 litres of water per square metre. Seed sowing followed the protocol established by the TRB Crop Production Department. Seeds were surface-sterilised by immersion in 5% sodium hypochlorite for 30 seconds then rinsed three times in sterile distilled water. Each seed was sown individually in a 15 cm diameter pot filled with the fumigated soil medium. Each plot comprised 15 plants yielding a total plant population of 450, a number designed to permit three rounds of destructive sampling across the trial period.

3.5 Nematode Inoculum Preparation

Nematode inoculum was prepared following the standard TRB Nematology Department protocol. Tomato plants with confirmed *M. javanica* infections were carefully removed from their pots and roots were washed under running tap water. Cleaned roots were cut into 3-5 cm segments and placed in a beaker containing 5% sodium hypochlorite, then agitated for three to five minutes to release eggs. The resulting suspension was sequentially sieved through nested 45 micrometer and 38 micrometer sieves to collect the egg fraction. Eggs retained on the 38 micrometer sieve were rinsed with distilled water and transferred to a clean beaker. The 45 micrometer sieve roots underwent a second extraction cycle to recover remaining eggs. The final suspension was diluted to a standard concentration of 1 000 eggs per ml following microscopic counting.

3.6 Nematode Inoculation

Plants were inoculated two weeks after sowing. The assigned inoculum concentrations per plant were determined by randomisation. Inoculation was carried out in moist but not waterlogged soil to prevent inoculum run-off. Three evenly spaced holes were created around each plant using a fine rod, and the inoculum suspension was continuously stirred on a magnetic plate at low speed to maintain egg homogeneity. The prescribed volume was delivered to each plant through the three holes using a 10 ml pipette and holes were immediately backfilled with soil. Plants were left unwatered for 24 hours post-inoculation to minimise leaching of inoculum from the root zone.

3.7 Maintenance of Plants

Plants were maintained under glasshouse conditions for 10 weeks post-inoculation to allow sufficient time for nematode stress responses to develop and observed. Water was applied to field capacity as required. Fertiliser was applied according to TRB recommendations, given the absence of established chia-specific fertility programmes for Zimbabwe. Compound C

fertiliser was applied at sowing at 2 g per pot, ammonium nitrate was subsequently side-dressed at 42 days after sowing at 5 g per plant. Weed management was done by hand pulling whenever weeds emerged in the planting pots.

3.8 Data Collection

Plant height was recorded at 4, 6, 8 and 10 WAI. Destructive assessments were carried out at 6, 8 and 10 WAI, with five plants removed per plot per session. At each harvest, roots were examined for galling using the Daulton and Nusbaum (1961) 0-8 galling scale, where 0 indicates no galling and 8 indicates complete root destruction. Harvested stalks were sun dried and dry weights determined at 6, 8 and 10 WAI. At 10 WAI, seeds were harvested from five remaining plants per plot and weighed to assess treatment effects on seed yield.

3.9 Root-knot galling scale

Galling score	Description
0 _____	No gall
1 _____	Traces of infection (less than 5galls)
2 _____	More than 5 galls less than 10 galls
3 _____	11 to 30 galls
4 _____	31 to 50 galls
5 _____	51 to 75 galls (coalition of galls)
6 _____	75 to 100 galls (root extensively damaged)
7 _____	> 100 galls (severe root damage)
8 _____	Root completely damaged (dead plant)

3.10 Data analysis

The data was collected on plant height, root knot galling scores, stalk dry weight and grain weight produced per plant. The data collected was analysed using analysis of variance (ANOVA) using GenStat (21st Version) and the Fisher's least significant difference (LSD) test at 0.05 probability level was used where the means are significantly different.

CHAPTER 4

Results

4.1 Effects of *Meloidogyne javanica* infection on plant height of chia.

At 4 weeks after inoculation (WAI), there were no significant differences ($p = 0.228$) in plant height between the untreated control and the plants inoculated with different concentrations of *Meloidogyne javanica* (Table 4.1, Appendix 2.1).

At 6 WAI, there were significant differences ($p < 0.001$) in plant height between the different treatments. The untreated control had significantly taller plants than all other treatments. However, there were no significant differences in plant height between the plants inoculated with 20 000 eggs and the plants inoculated with 10 000 eggs. Also, there were no significant differences in plant height between the plants inoculated with 5 000 eggs and the plants inoculated with 15 000 eggs. The plants inoculated with 25 000 eggs were significantly shorter than all other treatments (Table 4.1).

At 8 WAI, there were significant differences ($p < 0.001$) in plant height across all the treatments. The untreated control had significantly taller plants than all other treatments while the plants inoculated with 25 000 eggs were significantly shorter than plants from all the other treatments (Table 4.1).

At 10 WAI, there were significant differences ($p < 0.001$) in plant height among the different treatments. The untreated control had significantly taller plants than all other treatments. However, there were no significant differences in plant height between the plants inoculated with 20 000 eggs and the plants inoculated with 25 000 eggs. Also, there were no significant differences in plant height between the plants inoculated with 20 000 eggs and the plants inoculated with 15 000 eggs. The plants inoculated with 5 000 eggs and 10 000 eggs were significantly different from all other treatments (Table 4.1, Appendix 2.4).

Table 4.1: Effects of *Meloidogyne javanica* infection on plant height (cm) of chia at 4, 6, 8 and 10 weeks after inoculation (WAI).

Treatment	4 WAI height	6 WAI height	8 WAI height	10 WAI height
10000 eggs	52.4	69.7 ^b	97.6 ^d	135.0 ^c
15000 eggs	51.2	70.4 ^c	95.0 ^c	132.0 ^b
20000 eggs	52.6	69.9 ^b	93.2 ^b	130.2 ^{ab}
25000 eggs	51.8	67.9 ^a	90.8 ^a	128.6 ^a
5000 eggs	52.3	70.8 ^c	100.6 ^e	137.3 ^d
untreated	53.0	72.8 ^d	101.6 ^f	140.5 ^e
F-prob	0.228	<0.001	<0.001	<0.001
LSD	1.50	0.52	0.73	1.96
SED	1.14	0.39	0.56	1.48
CV(%)	2.20	0.60	0.60	1.10

*Means followed by the same letter in a column are not significantly different at $p \leq 0.05$.

4.2 Effects of *Meloidogyne javanica* infection on stalk dry weight of chia.

At 6 WAI, there were no significant differences ($p = 0.074$) in stalk dry weight between the treatments (Fig 4.1; Appendix 2.5).

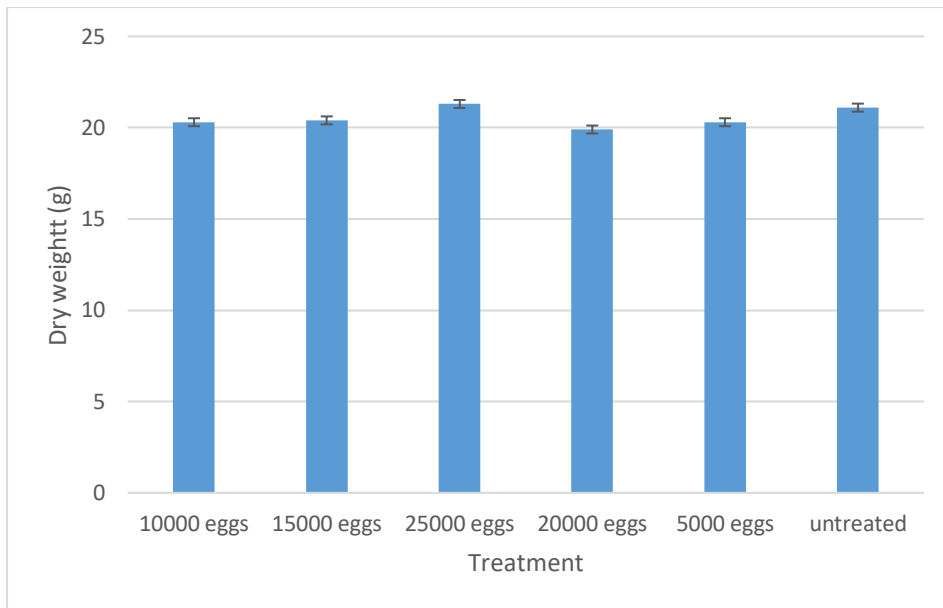


Figure 4.1: Effects of *Meloidogyne javanica* infection on stalk dry weight in chia at 6 weeks after inoculation.

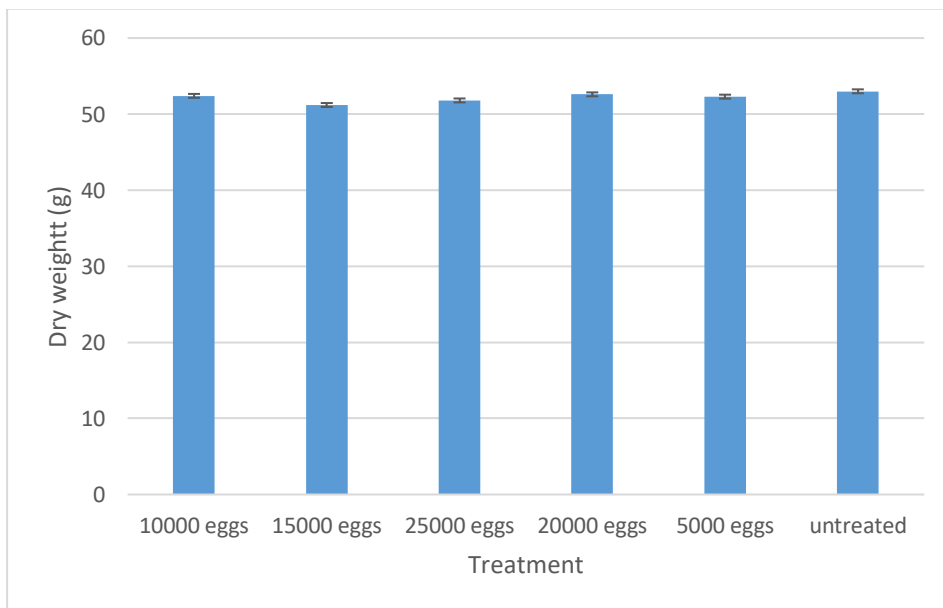


Figure 4.2: Effects of *Meloidogyne javanica* infection on stalk dry weight of chia at 8 weeks after inoculation.

At 8 WAI, there were no significant differences ($p = 0.228$) in stalk dry weight between the untreated control and the plants inoculated with different rates of *Meloidogyne javanica* inoculum (Appendix 2.6).

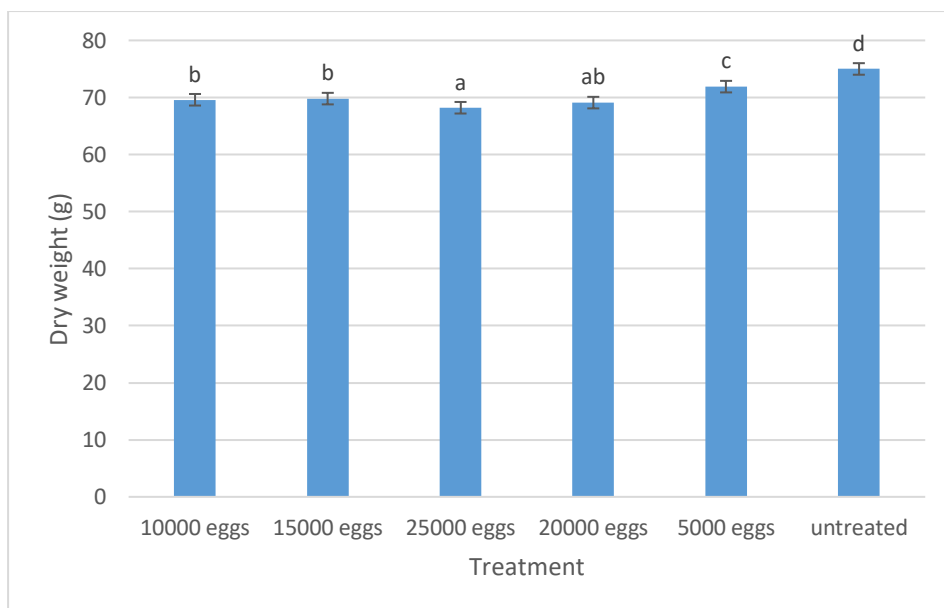


Figure 4.3: Effects of *Meloidogyne javanica* infection on stalk dry weight of chia at 10 weeks after inoculation.

At 10 WAI, there were significant differences ($p < .001$) in stalk dry weight between the treatments. The untreated control had significantly higher stalk dry weight than all other treatments. However, there were no significant differences in stalk dry weight between the plants inoculated with 10 000, 15 000 and 20 000 eggs. Additionally, there were no significant differences in stalk dry weight between the plants inoculated with 20 000 eggs and the plants inoculated with 25 000 eggs. The plants inoculated with 5 000 eggs had the second highest stalk dry weight (Fig 4.3; Appendix 2.7).

4.3 Root galling damage by *Meloidogyne javanica* in chia.

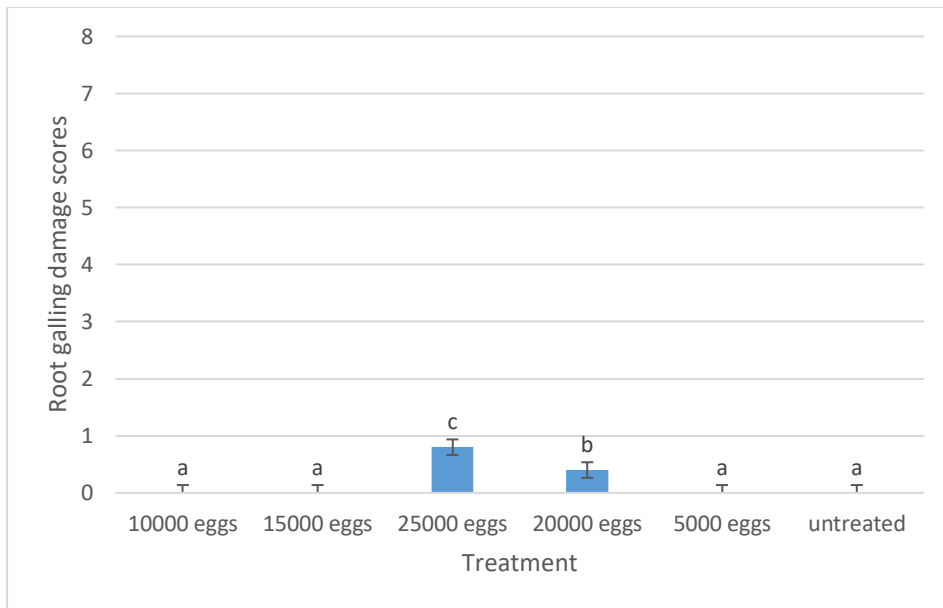


Figure 4.4: Root galling damage scores of *Meloidogyne javanica* in chia at 6 weeks after inoculation.

At 6 WAI, there were significant differences ($p < .001$) in root galling damage scores between the treatments. The plants inoculated with 5 000, 10 000 and 15 000 eggs were not significantly different from the untreated control, while those inoculated with 20 000 and 25 000 eggs were significantly different from the untreated control. Also, there were significant differences in root galling damage scores between the plants inoculated with 20 000 eggs and those inoculated with 25 000 eggs. The root galling damage scores in plants inoculated with 25 000 eggs were significantly higher than all other treatments (Fig 4.4, Appendix 2.8).

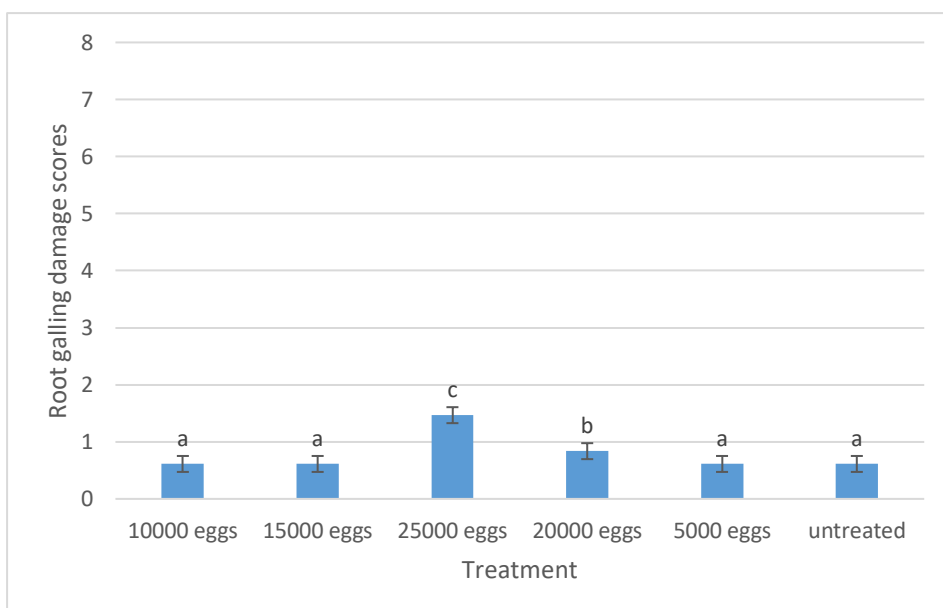


Figure 4.5: Root galling damage scores of *Meloidogyne javanica* in chia at 8 weeks after inoculation.

At 8 WAI, there were significant differences ($p < 0.05$) in root galling damage scores between the treatments ($p < 0.05$). The plants inoculated with 5 000, 10 000 and 15 000 eggs were not significantly different from the untreated control, however those inoculated with 20 000 and 25 000 eggs were significantly different from the untreated control. Additionally, there were significant differences in root galling damage scores between the plants inoculated with 20 000 eggs and those inoculated with 25 000 eggs. The root galling damage scores in plants inoculated with 25 000 eggs were significantly higher than all other treatments (Fig 4.5, Appendix 2.9).

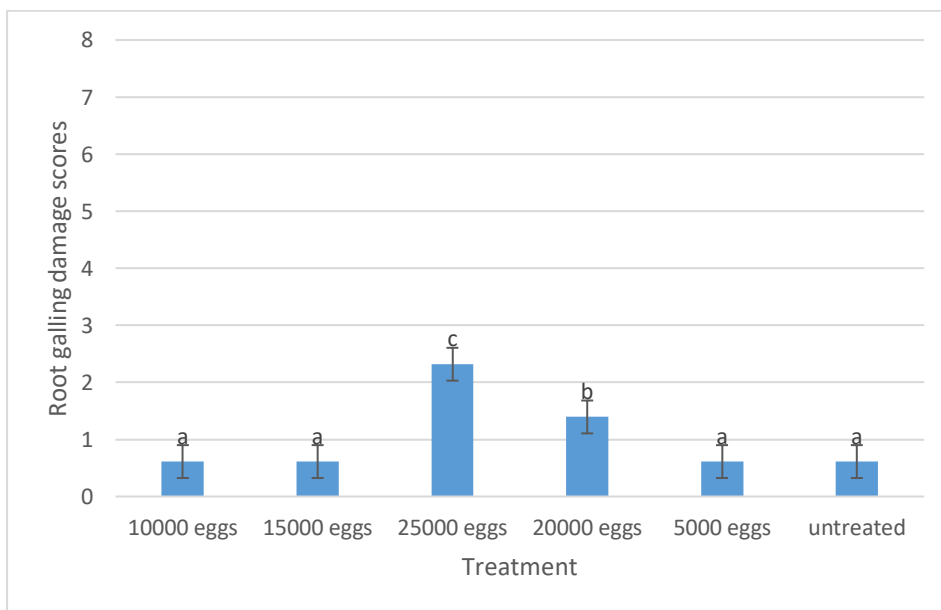


Figure 4.6: Root galling damage scores of *Meloidogyne javanica* in chia at 10 weeks after inoculation.

At 10 WAI, there were significant differences ($p < 0.05$) in root galling damage scores between the treatments ($p < 0.05$). The plants inoculated with 5 000, 10 000 and 15 000 eggs were not significantly different from the untreated control, however those inoculated with 20 000 and 25 000 eggs were significantly different from the untreated control. Additionally, there were significant differences in root galling damage scores between the plants inoculated with 20 000 eggs and those inoculated with 25 000 eggs. The root galling damage scores in

plants inoculated with 25 000 eggs were significantly higher than all other treatments. (Fig 4.6, Appendix 2.10).

4.4 Effects of *Meloidogyne javanica* infection on the weight of seeds (g) produced per plant in chia.

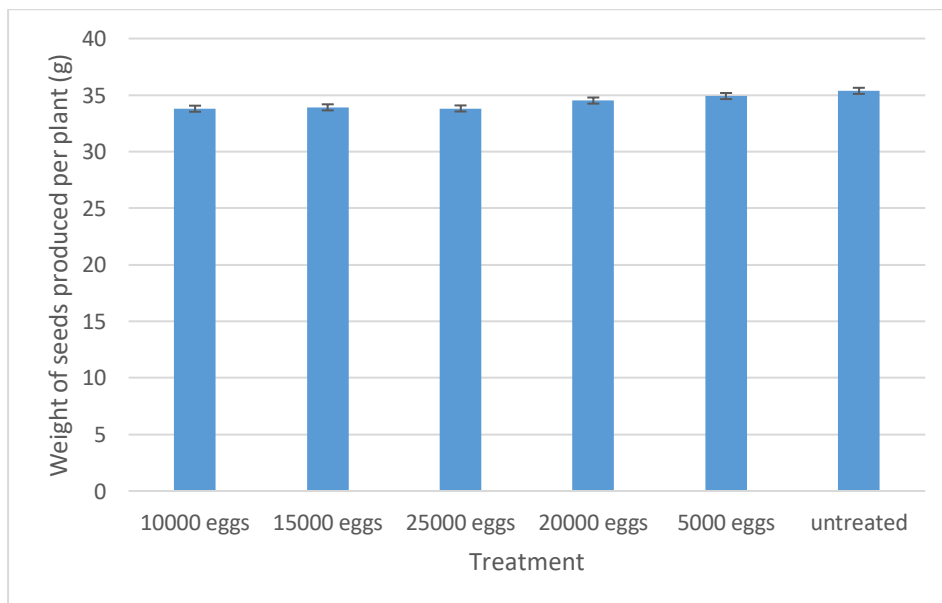


Figure 4.7: Effects of *Meloidogyne javanica* infection on the weight of seeds (g) produced per plant in chia.

There were no significant differences ($p = 0.162$) in the weight of seeds produced per plant between the untreated control and the plants inoculated with 5 000, 10 000, 15 000, 20 000 and 25 000 eggs (Appendix 2.11).

CHAPTER 5

Discussion

5.1 Plant height

Nematode inoculum had no significant effect on plant height during the first four weeks after inoculation, this was likely because the *M. javanica* populations were still establishing within root tissue. From 6 WAI onwards, a clear and progressive height reduction became evident in inoculated plants with the degree of stunting correlating positively with inoculum concentration. This finding is consistent with the well documented behaviour of nematode populations which amplify progressively over time as reproduction cycles accumulate in the root system. As Jones *et al.* (2022) noted, it is the cumulative impact of large nematode numbers rather than individual parasite action that drives economically significant crop damage. *M. javanica* disrupts host vascular tissue compromising both water movement and nutrient translocation to actively growing shoot apices (Mantelin *et al.*, 2022, El-Sappah *et al.*, 2021). As the supply of carbohydrates and mineral nutrients to meristematic zones diminishes, cell division and elongation are progressively slowed resulting in the visible stunting documented across this trial. Even moderate nematode pressure of 5 000 eggs per plant produced measurable growth suppression by mid-trial, shows that early season nematode management is critical in chia production systems.

5.2 Stalk Dry Weight

Meloidogyne javanica inoculation did not significantly affect stalk dry weight during the first eight weeks of the experiment reflecting the physiological reality that measurable biomass impacts require both sufficient nematode population build up and sustained stress exposure. However significant differences were observed at 10 WAI effect was apparent with the untreated control yielding the highest stalk dry weight while higher inoculum concentrations led to lower dry matter accumulation. The similar dry weights between the 20 000 and 25 000 egg treatments at this stage may suggest a saturation effect whereby root damage is so extensive across both treatments that biomass outcomes are similarly depressed regardless of the marginal inoculum difference. The underlying physiology operates through two primary pathways like, the plant diverts photosynthate toward defence responses and nematode feeding sites rather than vegetative growth (El-Sappah *et al.*, 2021, Ali *et al.*, 2022) and second severe nematode-induced root damage impairs water uptake to the degree that photosynthetic efficiency is significantly compromised directly curtailing dry matter production (Kumar *et al.*, 2021).

5.3 Root Gallling Damage

Root gallling damage scores remained low across all treatments throughout the experiment period, ranging from only 0 to 2 on a 0-8 scale. While plants inoculated at 25 000 eggs per plant recorded the highest scores even these most heavily challenged plants exhibited only trace to minimal galling a finding that strongly implies chia possesses an inherent capacity to limit nematode establishment and feeding site development even under high inoculum pressure (Hussain *et al.*, 2023, Sharma *et al.*, 2024). Possible mechanism is the hypersensitive response that is a rapid localised cell death reaction triggered at the nematode feeding site that denies the J2 the metabolically active giant cells it requires to complete its life cycle (Ali *et al.*, 2022). The nematode starves without a functional feeding site and dies before reproducing thereby preventing population amplification and secondary galling.

Complementing this hypersensitive defence, chia may also use chemical defence compounds to protect itself against nematode attack. Hussain *et al.* (2023) reported nematicidal activity in chia associated with the production of systemic defence related compounds such as salicylic acid, which primes uninfected root tissues against J2 penetration and restricts the development of all subsequent nematode stages. Sharma *et al.* (2024) further documented that chia root chemistry - particularly phenolic compounds and flavonoids exerts direct toxic and

movement inhibitory effects on *Meloidogyne* species while root exudates may additionally suppress egg hatching. Together, these chemical and physiological defence mechanisms create an environment broadly inhospitable to nematode colonisation. This may explain why only low levels of galling were observed, even at high inoculum levels.

5.4 Weight of Seeds (g) Produced Per Plant

M. javanica inoculum level concentrations did not significantly affect seed weight per plant in chia. This result aligns with the pattern of minimal root galling and is consistent with published evidence that plants capable of effectively restrict the nematode establishment can sustain normal reproductive output despite nematode pressure (El-Sappah *et al.*, 2021, Khan *et al.*, 2022). From a practical standpoint, this research is particularly encouraging farmers that chia's seed productivity is not affected by *M. javanica*. The primary economic output of the crop remains resilient under *M. javanica* challenge strengthening its value as a rotation partner in fields where nematode populations may be elevated.

CHAPTER 6

Conclusion and Recommendations

6.1 Conclusions

The results of this research support the conclusion that *Meloidogyne javanica* infection causes meaningful reductions in both plant height and stalk dry weight of chia under sustained nematode pressure with plant height effects becoming apparent from 6 WAI and stalk dry weight effects becoming significant at 10 WAI. Importantly, however, the nematode had no appreciable effect on root galling scores which remained exceptionally low throughout the entire trial period nor on seed weight per plant. The consistently minimal galling across all inoculum levels including the highest concentration of 25 000 eggs per plant, provides compelling evidence that chia possesses the capacity to suppress *Meloidogyne javanica* populations most likely through a combination of hypersensitive response and phytochemical defence mechanisms. This suppressive capacity, alongside the crop's unaffected seed productivity under nematode challenge positions chia as a promising component of integrated nematode management strategies in tobacco based farming systems in Zimbabwe.

6.2 Recommendations

Based on the results, tobacco farmers are encouraged to incorporate chia into their rotation programmes as a strategy for maintaining *Meloidogyne javanica* populations below economically damaging thresholds. Future research should consider the use of second stage juveniles (J2) rather than eggs as the inoculum source as the hatch rate of egg-based inoculum may vary under glasshouse conditions and introduce variability into dose response assessments. Multi site, multi-season field trials are also recommended to validate these glasshouse findings under the more variable conditions typical of commercial production environments.

References

Ayerza, R., & Coates, W. (2005). Chia: Rediscovering a forgotten crop of the Aztecs. University of Arizona Press.

Aguilar-Toala, J. E., Vidal-Limon, A., & Liceaga, A. M. (2022). Multifunctional analysis of chia seed (*Salvia hispanica* L.) bioactive peptides using peptidomics and molecular dynamics simulations approaches. *International Journal of Molecular Sciences*, 23(13), 7288.

Capitani, M. I., Spotorno, V., Nolasco, S. M., & Tomás, M. C. (2012). Physicochemical and functional characterization of by-products from chia (*Salvia hispanica* L.) seeds. *LWT – Food Science and Technology*, 45(1), 94–102.

Chia Growers Zimbabwe. (2019, October 30). The Soil.
<http://thesoil.co.zw/index.php/tag/chia-growers-zimbabwe/>

Chia Seeds: Health Benefits, Nutrients per Serving, Uses, Safety Information, and More. (n.d.). WebMD. Retrieved September 26, 2025, from
<https://www.webmd.com/diet/health-benefits-chia-seeds>

- Chimbishi, P. (2022). Land reform and smallholder agriculture in Zimbabwe. *African Journal of Agricultural Research*, 18(2), 103-115.
- Chivuraise, C., Mutambara., & Chamboko. (2011). Economics of smallholder tobacco production and implications of tobacco growing on deforestation in Hurungwe District of Zimbabwe. Unpublished MSc. Thesis. University of Zimbabwe, Harare.
- Coates, W., & Ayerza, R. (1996). Production potential of chia in northwestern Argentina. *Industrial Crops and Products*, 5(3), 229–233.
- Daulton, R. A. C. (1961). Soil fumigation and agronomic practices to control *Meloidogyne javanica* in tobacco in Southern Rhodesia. *Nematologica*, 10(1).
- Desaeger, J., Wram, C., & Zasada, I. (2020). New reduced-risk agricultural nematicides and their role in nematode management. *Journal of Nematology*, 52, 1-16.
- Diaz-Silveira, M. F., & Herrera, I. (1998). Susceptibility of tobacco varieties to root-knot nematodes. *Nematropica*, 28(1), 45-53.
- Dhandaydham, M., Charles, L., Zhu, H., Starr, J. C., Huguet, T., Cook, D. R., Prosper, J. M., & Opperman, C. (2008). Characterisation of root-knot nematodes resistance in *Medicago truncatula*. *Journal of Nematology*, 40(10), 46–54.
- Faske, T. R., & Starr, L. L. (2007). Cotton root protection from plant parasitic nematodes by abamectin treated seed. *Journal of Nematology*, 39(1), 27–30.
- Grancieri, M., Martino, H. S. D., & Gonzalez de Mejia, E. (2022). Chia seed (*Salvia hispanica* L.) as a source of proteins and bioactive peptides: A review. *Food Research International*, 156, 111298.
- Gowen, J. R., Ruabate, T. K., & Wright, J. G. (2005). Root-knot nematodes. Pest Advisory Leaflet No. 9. Secretariat of the Pacific Community.
- Handoo, Z. A., Skantar, A. M., Carta, L. K., & Erbe, E. F. (2005). Morphological and molecular characterization of a new root-knot nematode, *Meloidogyne thailandica* spp. (Nematoda: Meloidogynidae), parasitizing ginger (*Zingiber* spp.). *Journal of Nematology*, 37(3), 343–353.
- Hussey, R. S., & Barker, K. R. (1973). A comparison of methods of collecting inocula of *Meloidogyne* spp., including a new technique. *Plant Disease Reporter*, 57, 1025–1028.

- Johnson, C. S., Way, J., & Barker, R. K. (2005). Nematode parasite of tobacco. In M. Luc, R. A. Sikora, & J. Bridge (Eds.), *Plant parasitic nematodes in subtropical and tropical agriculture* (pp. 675–708). CABI International.
- Karavina, C., & Mandumbu, R. (2012). Phytoparasitic nematodes management post-methyl bromide: Where to for Zimbabwe? *Journal of Agricultural Technology*, 8(4), 1141–1160.
- Khan, M. R., Jain, R. K., Chule, T., & Pal, S. (2012). *Root-knot nematodes of India: A comprehensive monograph*. Venus Publishers.
- Levin, R. (2005). *Reproduction and identification of root-knot nematodes on perennial plants in Florida*. Thesis presented to the Graduate School of the University of Florida.
- Makunde, P. T., Mahere, T. S., & Dimbi, S. (2019). Root-knot nematode control on tobacco: Alternative to fumigant nematicides. Harare: Nematology Department, Tobacco Research Board Conference Paper, CORESTA Congress.
- Mapfumo, S. (2015). *Tobacco production and the environment*. The Herald Zimbabwe. Harare.
- Massawe, R. S. (2010). *Impact of nematode pest management strategy on nematode communities in tomato production systems in Zimbabwe*. Unpublished MSc. Thesis, University of Zimbabwe, Harare.
- Mazarura, U. (2004). *A guide to the use of the float tray system for tobacco seedling production in Zimbabwe*. Nehanda Publishers.
- Miller, S. A. (2007). Soil nematode community, organic matter, microbial biomass and nitrogen dynamics in field plots transitioning from conventional to organic management. *Applied Soil Ecology*, 37, 256–366.
- Moens, M., Perry, R. N., & Starr, J. L. (2009). *Root-knot nematodes*. CABI.
- Muzhandu, R. T., Chinheya, C. C., Manjeru, P., & Dimbi, S. (2013). Use of edaphic factors to map the spatial distribution of root-knot nematodes in tobacco plantations. *Journal of Agricultural Research*, 8(20), 3946–3949.

Mwangi, J. M. (2011). Plant parasitic nematodes associated with cabbage in different agro-ecological zones in Nyandarua and Embu Counties. Unpublished MSc. Thesis, Kenyatta University, Nairobi.

Nyamapfene, K. W. (1991). Soils of tobacco. Nehanda Publishers.

Onkendi, E. M., Kiriuki, G. M., Marais, M., & Moleleki, L. N. (2014). The threat of root-knot nematodes (*Meloidogyne* spp.) in Africa: A review. *Journal of Nematology*, 39, 190–202.

Rich, J. R., & Thomas, W. D. (2005). Tobacco nematode management. Department of Entomology and Nematology, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. <http://edis.ifas.ufl.edu>

Robertson, J. (2011). Statistics on the Zimbabwean economy reconstruction: Present state, ongoing projects and prospects for reinvestment. Development Planning Division Working Paper Series 32. Development Bank of South Africa.

Shew, H. D., & Lucas, G. B. (1991). Compendium of tobacco diseases. American Phytopathological Society.

Sikora, R. A., Coyne, D., Hallmann, J., & Timper, P. (2018). Plant-parasitic nematodes in subtropical and tropical agriculture. CABI.

Smiley, R. (2005). Plant parasitic nematodes affecting wheat yield in Pacific Northwest. Oregon State University Extension Services.

Sukume, C., & Guveya, E. (2009). Improving input and output markets for smallholder farmers in Zimbabwe. Unpublished report.

Tekere, M., Hurungo, J., & Rusare, M. (2015). WTO agreement on agriculture: The implementation experience. Trade and Development Studies Centre, Harare.

Tips for Growing Chia Seeds Successfully in Zimbabwe. (n.d.). ShunCy. Retrieved September 26, 2025, from <https://shuncy.com/article/how-to-grow-chia-in-zimbabwe>

Tobacco Industry Marketing Board (TIMB). (2021). Annual Tobacco Statistics Report 2020. TIMB.

Tobacco Research Board. (2013). Varietal release document. Tobacco Research Board Annual Report.

Trueman, S. (2020). All about the tobacco plant. ThoughtCo. <https://thoughtco.com/the-botany-of-the-tobacco-plant-419203>

Ullah, R., Nadeem, M., Khalique, A., et al. (2016). Nutritional and therapeutic perspectives of chia (*Salvia hispanica* L.): A review. *Journal of Food Science and Technology*, 53(4), 1750–1758.

Where Do Chia Seeds Come From? The History Behind This Superfood. (2025, August 11). ChiaSeed.net. <https://chiaseed.net/where-do-chia-seeds-come-from-the-history-behind-this-superfood/>

APPENDICES

Appendix 1: Table 1 showing the random assignment of the treatments in the plots

Rep 1	10000eggs	5000 eggs	untreated	25000eggs	20000eggs	15000eggs
Rep 2	25000eggs	untreated	15000eggs	20000eggs	10000eggs	5000 eggs
Rep 3	15000eggs	10000eggs	5000 eggs	untreated	25000eggs	20000eggs
Rep 4	5000 eggs	20000eggs	10000eggs	25000eggs	15000eggs	untreated
Rep 5	untreated	5000 eggs	15000eggs	10000eggs	20000eggs	25000eggs

Appendix 2: Analysis of variance

2.1 Variate: Plant height 4 weeks after inoculation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	2.981	0.745	0.58	
Rep.*Units* stratum					
TREATMENT	5	9.803	1.961	1.52	0.228
Residual	20	25.771	1.289		
Total	29	38.555			

2.2 Variate: Plant height 6 weeks after inoculation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	0.2480	0.0620	0.40	
Rep.*Units* stratum					
TREATMENT	5	64.1667	12.8333	83.33	<.001
Residual	20	3.0800	0.1540		
Total	29	67.4947			

2.3 Variate: Plant height 8 weeks after inoculation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	0.6453	0.1613	0.52	
Rep.*Units* stratum					
TREATMENT	5	456.0387	91.2077	296.39	<.001
Residual	20	6.1547	0.3077		
Total	29	462.8387			

2.4 Variate: Plant height 10 weeks after inoculation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	11.395	2.849	1.30	
Rep.*Units* stratum					
TREATMENT	5	506.311	101.262	46.08	<.001
Residual	20	43.949	2.197		
Total	29	561.655			

2.5 Variate: Stalk dry weight 6 weeks after inoculation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	0.2133	0.0533	0.09	
Rep.*Units* stratum					
TREATMENT	5	7.2547	1.4509	2.39	0.074
Residual	20	12.1387	0.6069		
Total	29	19.6067			

2.6 Variate: Stalk dry weight 8 weeks after inoculation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	2.981	0.745	0.58	
Rep.*Units* stratum					
TREATMENT	5	9.803	1.961	1.52	0.228
Residual	20	25.771	1.289		
Total	29	38.555			

2.7 Variate: Stalk dry weight 10 weeks after inoculation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	1.5467	0.3867	0.62	
Rep.*Units* stratum					
TREATMENT	5	150.8000	30.1600	48.44	<.001
Residual	20	12.4533	0.6227		
Total	29	164.8000			

2.8 Variate: Root galling damage scores 6 weeks after inoculation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	0.46667	0.11667	1.52	
Rep.*Units* stratum					
TREATMENT	5	12.96667	2.59333	33.83	<.001
Residual	20	1.53333	0.07667		
Total	29	14.96667			

2.9 Variate: Root galling damage scores 8 weeks after inoculation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	0.10840	0.02710	1.44	
Rep.*Units* stratum					
TREATMENT	5	2.93606	0.58721	31.16	<.001
Residual	20	0.37686	0.01884		
Total	29	3.42132			

2.10 Variate: Root galling damage scores 10 weeks after inoculation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	0.027158	0.006790	1.00	
Rep.*Units* stratum					
TREATMENT	5	12.449308	2.489862	366.72	<.001
Residual	20	0.135792	0.006790		
Total	29	12.612258			

2.11 Variate: Weight of seeds produced per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	112.41	28.10	1.26	
Rep.*Units* stratum					
TREATMENT	5	199.26	39.85	1.78	0.162
Residual	20	446.55	22.33		
Total	29	758.22			

Appendix 3: Root-knot galling scale

Galling score	Description
0	No gall
1	Traces of infection (less than 5galls)
2	More than 5 galls less than 10 galls
3	11 to 30 galls
4	31 to 50 galls
5	51 to 75 galls (coalition of galls)

- 6 75 to 100 galls (root extensively damaged)
- 7 > 100 galls (severe root damage)
- 8 Root completely damaged (dead plant)



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