International Journal of Irrigation and Agricultural Development
Agricultural Science and Development
IJIRAD 10(1) [2026] [524 – 532]
IJIRAD
ISSN: 2616-1508
https://ijirad.org

Biochar Rates and Bio-Nematicide Effects on Tomato (*Solanum lycopersicum* L.) Growth, Yield and Root-Knot Nematodes (*Meloidogyne* spp.) Suppression in Northern Ghana

Christopher Agyemang[1*], Mohammed Mujitaba Dawuda[2], Abubakari Abdul-Halim[2], Venu Polineni[3], Glenda Polack[4], Alejandro Calderon-Urrea[5]

[1]*AC Research Services, P.O. Box TL 2463, Tamale, Ghana*
[2]*University for Development Studies, Faculty of Agriculture, food and Consumer Sciences Department of Horticulture, P. O. Box TL 1882, Tamale, Ghana*
[3]*Telluris Biotech India Pvt. Ltd., Hyderabad 500 033, India*
[4]*Telluris Envirotechnology, Fresno, CA 93711, USA*
[5]*Department of Biology, California State University, Fresno, CA 93740, USA*

**Corresponding Author's Email: agyenchris2@gmail.com*

ARTICLE INFO

Article History:
Received: **Feb. 7, 2026**
Received in revised form: **June 5, 2026**
Accepted: **June 24, 2026**

Keywords:
Biochar rates, Peptide-based bionematicide, Tomato crop, Root-Knot nematodes, Rice husk biochar

DOI: https://doi.org/10.47762/2026.964x.167

ABSTRACT

Root-knot nematodes (Meloidogyne spp.) are among the most destructive pests limiting tomato production, particularly in tropical regions. Two experiments (pot and field trials) were conducted at the University for Development Studies, Nyankpala, Ghana, to evaluate the effects of different biochar amendment rates on the efficacy of a peptide-based bionematicide (Nemanol) in suppressing root-knot nematodes and improving tomato yield. The pot experiment comprised five (5) treatments; 0, 1, 3, and 5% biochar (w/w), applied with or without 5mL of peptide solution. Treatments were arranged in a completely randomized design with four (4) replications. The field experiment evaluated biochar application rates of 0, 2, 4, and 6 t/ha combined with 20 mL of peptide solution per plant, using a randomized complete block design with three (3) replications. In both experiments, treatments significantly (p<0.05) affected most measured growth, yield and nematode infestation indices. Low biochar application rates (1–3% in the pot experiment and 2 t/ha in the field experiment) significantly enhanced plant growth, canopy spread, flowering, and fruit yield compared with the control and higher biochar rates (5% in pots and 6 t/ha in the field). The combined application of 1% biochar and peptide increased plant height by 28.9%, while 2 t/ha biochar combined with peptide reduced root galling severity by 58.3% relative to untreated soil. Biochar amendment also reduced soil pH to a range more favourable for tomato growth. Overall, the combination application of moderate biochar rates and a peptide-based bionematicide effectively suppressed root-knot nematode populations and improved tomato growth and yield. These findings suggest that applying 2 t/ha of rice husk biochar together with 20mL per plant of peptide-based bionematicide can be recommended as an effective management strategy for root-knot nematodes control in tomato production in the study area.

INTRODUCTION

Root-knot nematodes (*Meloidogyne* spp.) are among the most destructive soil-borne pests affecting a wide range of agricultural crops, including tomato (*Solanum lycopersicum* L.), cabbage, and carrot (Sahebani & Hadavi, 2020). Root-knot nematode infestation typically causes gall formation on roots, reduced nutrient uptake, stunted growth, decreased yield, and may lead to complete crop failure under severe conditions (Sikora et al., 2005). The management of root-knot nematodes has traditionally relied on synthetic nematicides such as Furadan and Carbofuran (Olabiyi., 2008). Although these products are effective, their use is increasingly discouraged due to concerns about toxicity, persistence in the environment, and potential risks to human and animal health (Molinari, 2011). In Ghana, studies have explored alternative strategies using organic soil amendments such as chicken manure (Dawuda et al., 2011) and green manures like *Mucuna pruriens* (Atta-Poku *et al.,* 2014). While these organic materials can suppress nematode populations and improve soil fertility, they often require large quantities for effective control, making them labour-intensive and expensive for large scale vegetable crop production.

Peptide-based nematicides have recently emerged as environmentally friendly and cost-effective alternative for nematode management. Peptides have demonstrated strong activity against plant-parasitic nematodes and pathogenic fungi, while posing minimal ecological risk (Aulakh and Regmi, 2013; Vanzolini et al., 2022). At the same time, biochar a carbon-rich product of biomass pyrolysis has gained attention as a soil amendment that can enhance soil fertility and modify physical and chemical soil properties, including pH, cation exchange capacity, and moisture retention (Novak et al., 2009; Jeffery et al., 2011; Igalavithana et al., 2016). It has been hypothesized that biochar may influence the efficacy of peptide-based nematicides by altering soil conditions that affect nematode activity and plant response. The present study therefore investigated the combined effects of biochar amendment rates and a peptide-based nematicide (Telluris) on root-knot nematode infestation, plant growth, and yield performance of tomato.

MATERIALS AND METHODS

Study Area

Two (2) experiments were conducted at the University for Development Studies (UDS), Nyankpala Campus, Ghana (Figure 1). The pot experiment was carried out in the planthouse of the Department of Horticulture over a two-month period. The field experiment was conducted in the Horticulture Department Garden over a period of three months. Soil sampling and nematodes identifications were performed in the Nematology Laboratory of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi. Tomato (*Solanum lycopersicum* L.) was selected as the test crop due to its economic importance and high susceptibility to root-knot nematodes (*Meloidogyne* spp.) in Ghanaian vegetable production systems.

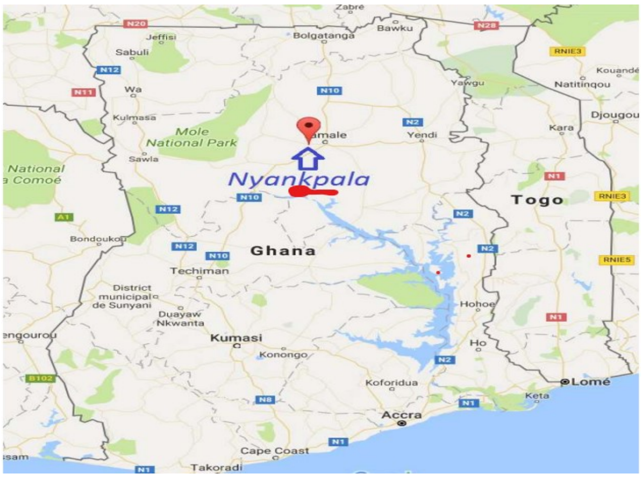

Figure 1. Map Showing the Experimental Site

Pot and Field Experiment Setup

The pot experiment was arranged in a randomized complete block design (RCBD) with five (5) treatments and three (3) replications. Rice husk biochar was produced using the Kuntine pyrolysis method and sieved through <2 mm mesh. The treatments consisted of varying rates of biochar combined with a peptide-based bionematicide (Telluris) as follows: Control (no biochar and no peptide), Soil + 5 mL peptide, Soil + 1% biochar + 5 mL peptide, Soil + 3% biochar + 5 mL peptide, and Soil + 5% biochar + 5 mL peptide. A naturally root-knot nematode infested soil was collected from the 'Water Works' Vegetable Farms in Tamale and homogenized with the appropriate biochar quantities. Each pot was filled with 5 kg of soil, seeded directly with two tomato seeds per pot, and treated with peptide solution immediately after sowing. The peptide-based nematicide (Nemanol 20% EC) was obtained from Telluris Biotechnology Limited, India. A second application of the peptide solution was made three weeks after the first application. The field experiment was laid out in a randomized complete block design (RCBD) with three (3) replications and five (5) treatments, namely; Control (no biochar or peptide), Soil + 20 mL peptide, Soil + 2 t/ha biochar + 20 mL peptide, Soil + 4 t/ha biochar + 20 mL peptide, and Soil + 6 t/ha biochar + 20 mL peptide. The field (14 × 8 m) was divided into 15 plots (2 × 2 m) separated by 1 m alleys. Biochar was mixed into the soil prior to transplanting at 2t, 4t and 6t per hectare. The peptide solution (20 mL per planting hole) was applied 24 hours before transplanting and repeated at 21 days after transplanting.

Data Collection and Analysis

Germination, growth, yield, and nematode indices were measured using standard procedures. Growth indices included plant height, leaf number, and stem diameter. In addition, days to flowering and fruiting, fruit number, fruit weight and yield were measured. Nematode population density, galling severity using the (Bridge & Page, 1980) rating from 1-5 where 1= no galling, 2= slightly galling, 3= mild galling, 4= moderate galling and 5= severe galling, and egg counts were determined at 70 days after sowing. Soil pH (1:2.5 soil–water) and bulk density were also measured. Data collected were analyzed using analysis of variance (ANOVA), and treatment means were separated by the least significant difference (LSD) test at a 5% probability level.

RESULTS AND DISCUSSION

Nematode Population in Tamale 'Gumbihini' Soil Sample

Soil nematode assay was conducted using soil samples collected from the 'Gumbihini' Vegetable Farms. The results of the soil assay showed that *Meloidogyne* spp. (root-knot nematodes) were dominant, followed by *Pratylenchus* and *Helicotylenchus* spp., while *Aphelenchoides* and *Tylenchus* spp. occurred in very low numbers (Figure 2). Thus, farmers growing root-knot nematodes susceptible crops like tomato, okra and cabbages will have root-knot nematodes control as a challenge to deal in the location. This pattern is consistent with earlier reports from Ghana, where high populations of root-knot nematodes have been documented in vegetable-producing soils (Adomako et al., 2017). The high incidence of *Meloidogyne* spp. indicates that farmers growing tomato, okra and cabbage in the area are likely to suffer from low yields due to the adverse effects of root-knot nematodes.

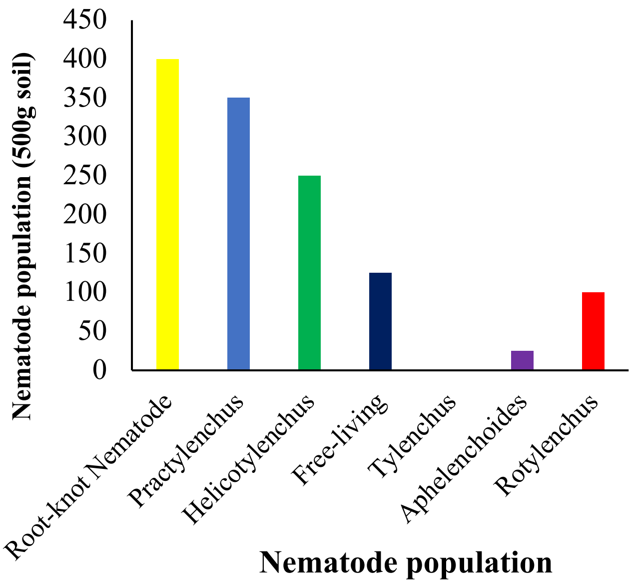

Figure 2 Nematode population density (per 500 g soil) in naturally infested vegetable field from 'Gumbihini' Tamale, Ghana

Effect of Biochar and Peptide Application on Soil pH

The results showed that the application of biochar and peptide based nematicide significantly (p = 0.002) affected soil (Figure 2). The control (only soil) and Soil + Peptide treatments gave the highest soil pH values (almost 7.0), while the 1%, 3%, and 5% biochar + peptides treatments decreased the pH levels. The higher biochar rates (3% and 5%) also decreased soil pH from near neutral to slightly acidic conditions, which are more favourable for the growth of tomato plants. This shows that biochar amendment can regulate soil pH towards the optimal range for increased nutrient availability and root functioning in tomato plants. Igalavithana et al. (2016) and Elad et al. (2011) earlier reported that biochar can modify soil pH by increasing organic acid formation and enhancing microbial activity, resulting in better nutrient solubility and uptake. In contrast, treatments without biochar (Only Soil and Soil + Peptides) maintained higher soil pH levels, suggesting that biochar incorporation buffered the soil environment and prevented alkalinity buildup. These results support the findings of Novak et al. (2009), who observed that biochar-amended soils often stabilise around pH levels optimal for vegetable crops.

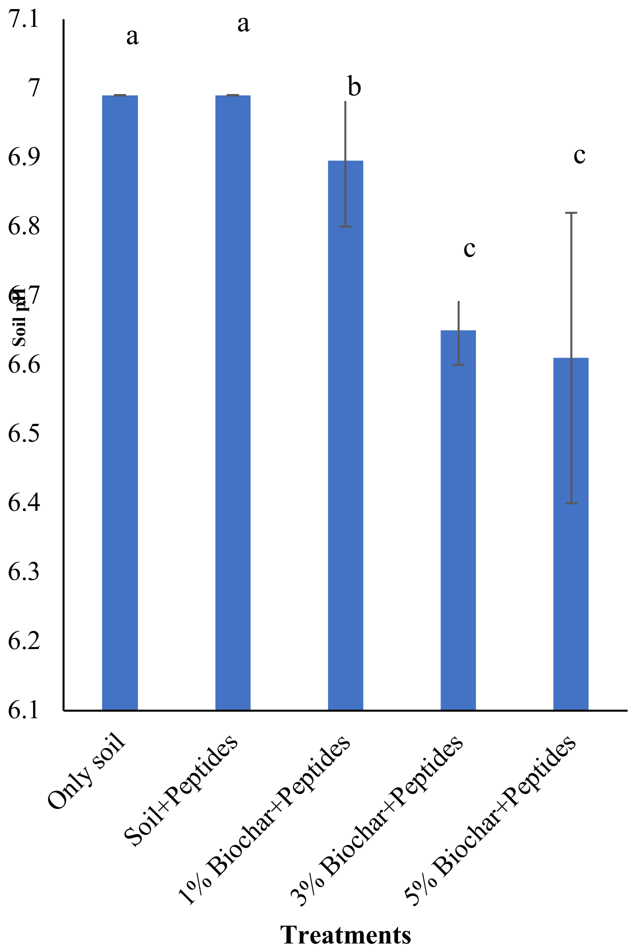

Figure 3. Effect of biochar and peptide application on soil pH at 70 days after sowing. Bars represent standard deviations

Effect of Biochar and Peptide Application on Germination and Plant Growth

The combined application of biochar and a peptide-based nematicide (Telluris) significantly ($p< 0.001$) improved germination and growth of tomato compared with untreated soil (Figures 4-8). The best responses were observed at low to moderate biochar rates. Germination was slightly higher under the 3% biochar + peptides treatment (Figure 4), possibly due to better soil aeration and moisture retention. Novak et al. (2009) reported similar effects of biochar on soil structure and seedling emergence. Vegetative growth parameters such as plant height (Figure 5), leaf number (Figure 6), stem diameter (Figure 7), and canopy spread (Figure 8) all increased significantly under the 1–2 t/ha biochar + peptides treatments. These effects can be attributed to improved soil fertility, nutrient retention, and effective root-knot nematode control. Igalavithana et al. (2016) found that biochar enhanced nutrient availability, while Lima et al. (2021) reported that peptide-based nematicides improved root health and nutrient uptake. In contrast, higher biochar rates slightly limited growth, as noted by (Lehmann et al., 2011). This suggests that the application of moderate biochar levels improve nutrient use and promote faster growth and reproductive development.

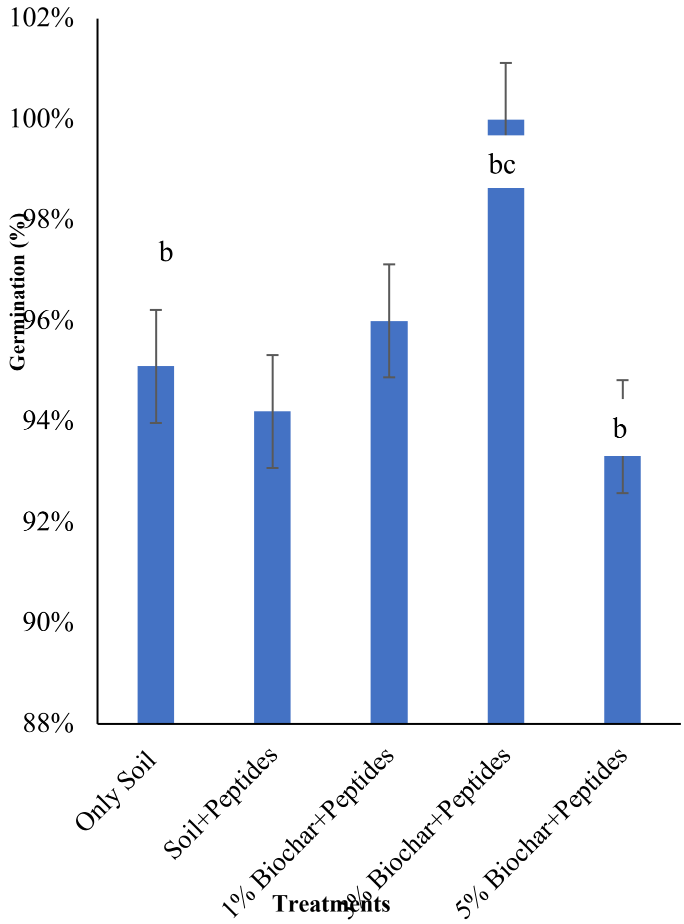

Figure 4. Effect of different concentrations of biochar and peptide on germination of tomato seed. Bars represent standard deviations

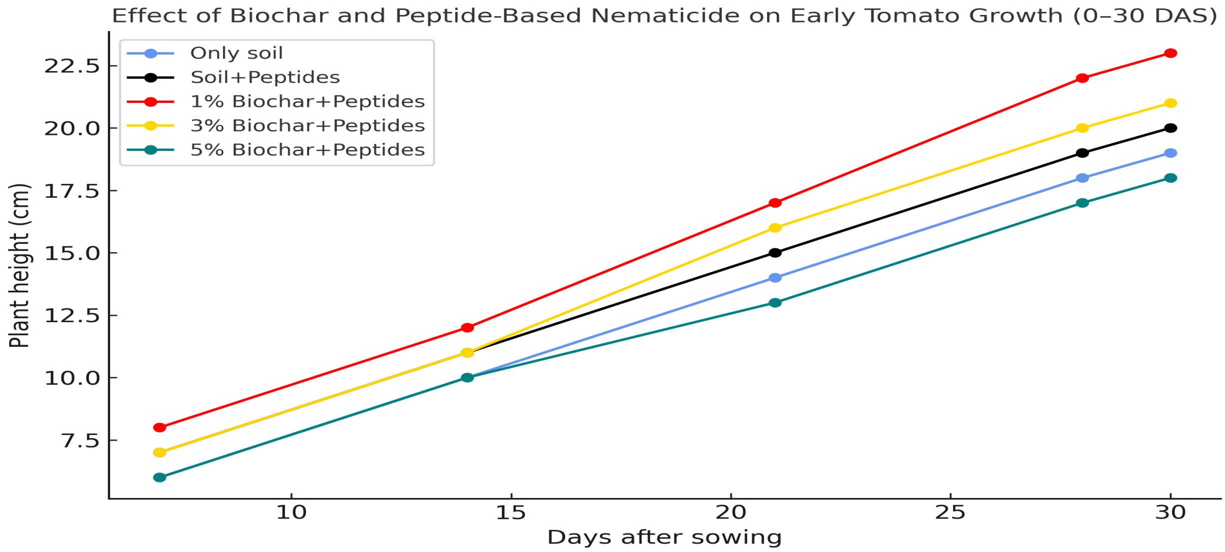

Figure 5. Effect of biochar and peptide application on plant height 30 days after sowing

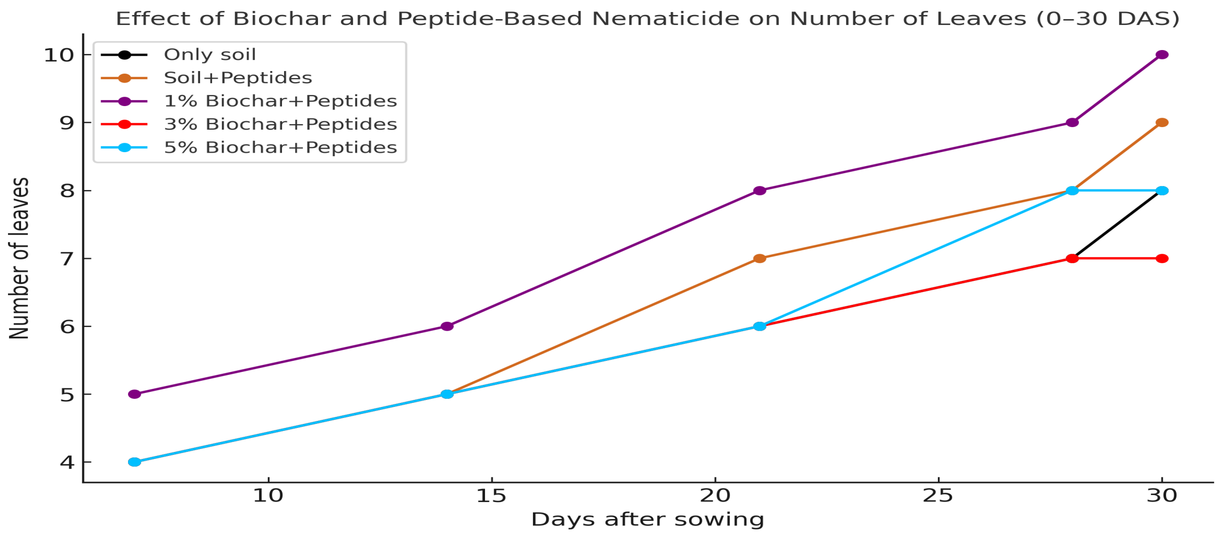

Figure 6. Effect of biochar and peptide application on number of leaves per plant 30 days after sowing

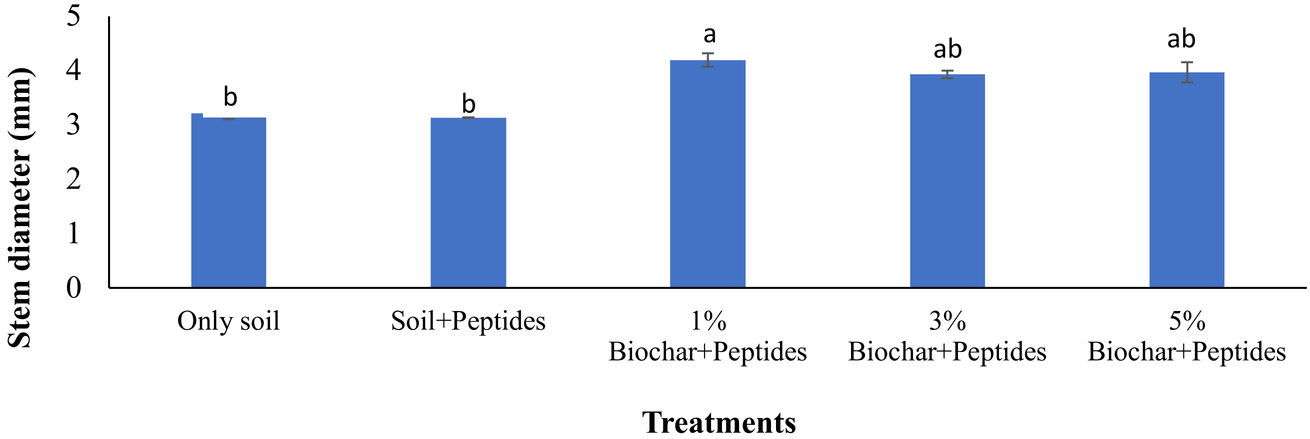

Figure 7. Effect of biochar and peptide application on stem diameter at 70 days after sowing. Bars represent standard deviations

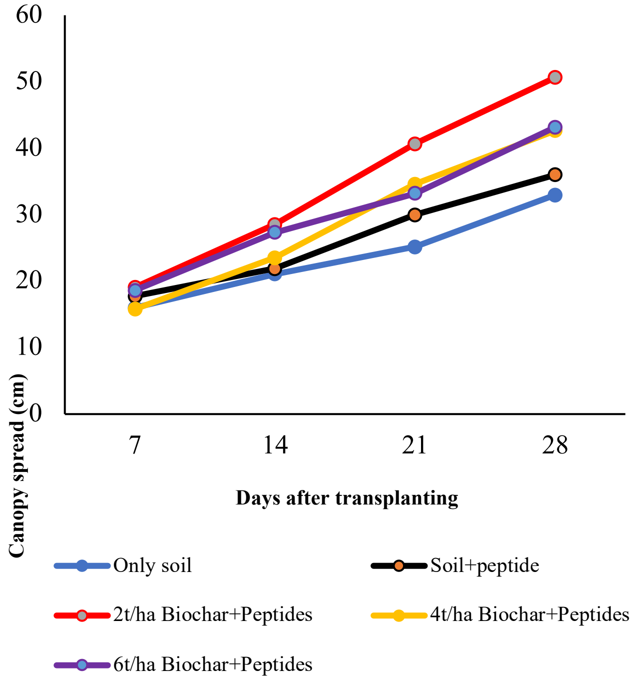

Figure 8. Effect of biochar and peptide application on canopy spread in tomato

Effect of biochar and peptide application on root-knot nematodes performance

The treatments significantly ($p < 0.001$) affected the root-knot nematode population in soil, gall count in root, egg count and severity of galling in roots at 70 days after sowing (Table 1). The 3% biochar + peptides treatment produced the lowest average galling index (1.78) and greatly reduced nematode infestation. The rating of below 2 is an indication that fewer galls which were difficult to find with an unaided eye occurred on the roots. The untreated soil (control) which recorded an average gall severity rating of 3.05 showed that the galling had affected more than 50% of the root system. The lower rates of application of biochar (1%, 3% and 2 t/ha) improved soil structure and enhanced the effectiveness of the *Telluris* peptide-based nematicide against root-knot nematode.

Moreover, these (1%, 3% and 2 t/ha) enhanced the effectiveness of the peptide applied in the root zone which probably triggered calcium signaling and synthesizing defensive proteins at the root tips of the plants to hinder the activities of root-knot nematode in the soil and in the roots as explained by (Huffaker *et al.,* 2013). Kim *et al.* (2017) observed increased galling and egg-mass formations of *M. incognita* were derived from the increased penetration rates in sandy soil conditions, which provided sufficient aeration due to coarse soil nature for the nematodes, leading to their mobility increased for the enhanced root penetration. In the current experiment, the biochar amendment slightly decreased soil bulk density and enhanced the effectiveness of the *Telluris* peptide-based nematicide against root-knot nematodes. In an experiment conducted by Elad *et al.* (2011), it was reported that the application of 1.2 % biochar in a potting medium effectively suppressed nematode development in rice roots. They further explained that the increased plant resistance was associated with biochar-primed H_2O_2 accumulation as well as with the transcriptional enhancement of genes involved in the ethylene (ET) signaling pathway (Elad et al., 2011). In another experiment, Elad et al. (2011) found that biochar had a high sorption capacity for dichloropropene, a strong anti-nematode fumigant.

As a result, biochar amendment to the soil could increase the required dose of dichloropropene to efficiently control nematodes. Lehmann et al. (2011) reported that biochar does not contain an indigenous consortium of microorganisms that can potentiate disease suppression, and the potential methods by which biochar induces systemic plant defenses against microbes. The suppression of soil pathogens by biochar may stem from several mechanisms, including improved nutrient solubilisation and uptake, which helps enhance plant growth and resistance to the stresses caused by pathogens; microbe stimulation (Elad et al., 2011; Lehmann et al., 2011).

Table 1 Effect of biochar and peptide application on root-knot nematodes performance at 70 days after sowing

Treatments	Root-knot nematode population in soil	Galling count in roots	Root-knot nematode egg extraction from root	Severity of galling in roots
Only soil	10^{a}	14^{a}	4^{a}	4^{a}
Soil+Peptides	5^{b}	11^{b}	2^{b}	3^{b}
1% Biochar+Peptides	1^{c}	7^{d}	1^{c}	2^{c}
3% Biochar+Peptides	1^{c}	7^{d}	1^{c}	1^{d}
5% Biochar+Peptides	3^{bc}	8^{cd}	1^{c}	2^{c}
P- value	<.001	<.001	<.001	<.001
LSD	2.369	1.039	0.4904	0.2003

Values within columns with the same letters are not significant different from each other

Effect of biochar and peptide application on Flowering, Fruit Yield and Biomass

The combination of biochar and a peptide-based nematicide (Telluris) significantly ($p<0.001$) improved tomato flowering, fruit yield and root biomass (Tables 2 and 3). The 2 t/ha biochar + peptides treatment promoted early flowering and produced 65% more fruits than the control (Table 2). Similar findings were reported by Elad et al. (2011) and Kim et al. (2017), who found that moderate biochar enhanced flowering and fruit formation in vegetables. The findings in this experiment are in line with Novotny et al. (2009) and Lima et al. (2021), who observed that biochar and biological agents synergistically enhance plant health. The 2 t/ha biochar + peptides treatment produced the highest fruit weight per plot (Table 2) as well as the greatest root biomass (Table 3). This may be due to enhancement in soil fertility and nutrient retention, while the peptide nematicide checked the adverse effects of the root-knot nematodes. Similar yield increases with biochar and biological treatments were reported by Elad et al. (2011) and Igalavithana et al. (2016), who observed that biochar improved soil structure and nutrient availability. Likewise, Lima et al. (2021) found that peptide-based nematicides promoted healthy root development and higher productivity. Root biomass also increased significantly under the 2 t/ha biochar + peptides treatment due to improved soil aeration and root protection. This agrees with Novak et al. (2009) and Kim et al. (2017), who found that biochar enhanced root growth and nutrient uptake. Although shoot weights did not vary significantly, plants with stronger roots generally produces higher fruit yields, supporting the view of Novotny et al. (2009) that biochar-amended soils promote balanced vegetative and reproductive growth. Overall, moderate biochar application (2 t/ha) combined with peptide-based nematicide improved both fruit yield and root development, indicating that their integration enhances soil health, nutrient efficiency, and sustainable tomato production.

Table 2. Effect of biochar and peptide application on tomato flowering and yield

Treatments	Days to first flower set	Days to 50% flowering	Days to first fruit set	Fresh fruit weight (g/plot)
Only soil	24.^{ab}	31.5^{a}	36^{a}	132.2^{b}
Soil+Peptides	26^{a}	28^{ab}	37^{a}	184.5^{ab}
2t/ha Biochar+Peptides	19^{d}	25^{b}	29^{c}	246.6^{a}
4t/ha Biochar+Peptides	22^{bc}	29^{a}	34^{ab}	138^{b}
6t/ha Biochar+Peptides	21^{cd}	28^{a}	32^{bc}	136.3^{b}
P- value	0.002	0.018	<.001	0.009
LSD	2.848	3.338	2.877	62.46

Values within columns with the same letters are not significant different from each other.

Table 3 Effect of biochar and peptide application on root and shoot biomass at 63 days after transplanting

Treatments	Fresh root weight (g plant^{-1})	Dry root weight (g plant^{-1})	Fresh shoot weight (g plant^{-1})	Dry shoot weight (g plant^{-1})
Only soil	63.1^{b}	12^{c}	481.7^{a}	126.8^{ab}
Soil+Peptides	141.2^{a}	16.45^{bc}	698.3^{a}	155.6^{a}
2t/ha Biochar+Peptides	148.1^{a}	23.53^{a}	705^{a}	165.7^{a}
4t/ha Biochar+Peptides	125.3^{a}	18.28^{ab}	630.1^{a}	155.4^{a}
6t/ha Biochar+Peptides	134.7^{a}	21.06^{ab}	654.9^{a}	159.3^{a}
P- value	0.037	0.01	0.22	0.684
LSD	54.89	5.668	227.5	20.23

Values within columns with the same letters are not significant different from each other

CONCLUSION

This study demonstrated that the combined application of biochar and a peptide-based nematicide effectively suppressed root-knot nematode activity and significantly improved tomato growth and yield. Biochar application rates of 1–3% in pot experiments and 2 t/ha under field conditions produced the most favorable outcomes. Biochar amendment also reduced soil pH to slightly acidic levels, which are optimal for tomato production.

The treatment combining 2 t/ha biochar with peptide-based nematicide consistently outperformed all other treatments, resulting in increased fruit yield and root biomass while markedly suppressing nematode activity. Overall, the integration of moderate biochar application rates with a peptide-based nematicide represents a sustainable and environmentally friendly strategy for managing root-knot nematodes.

Therefore, the combined application of moderate biochar levels (1–3% in pots or 2 t/ha in the field) with a peptide-based nematicide is recommended for the sustainable management of root-knot nematodes in the Nyankpala soil series of Ghana.

CONFLICT OF INTEREST

The authors have declared no conflict of interest regarding the publication of the paper.

REFERENCES

Adomako, J., Osei, K., Kankam, F., & Danso, Y. (2017). Limitations to peri-urban vegetable farming in Ghana: An overview of root-knot nematodes contribution. International *Journal of Sciences: Basic and Applied Research,* 36(3), 75–85.

Atta-Poku, P., Agyarko, K., Dapaah, H. K., & Dawuda, M. M. (2014). Influence of Mucuna pruriens green manure, NPK and chicken manure amendments on soil physico-chemical properties and growth and yield of carrot (*Daucus carota* L.). Journal of Agriculture and Sustainability, 5(1), 26–44.

Aulakh, J., & Regmi, A. (2013). Post-harvest food losses estimation: Development of consistent methodology. FAO Working Paper.

Bridge, J., & Page, S. L. J. (1980). Estimation of root-knot nematode infestation levels in roots using a rating chart. *Tropical Pest Management,* 26(3), 296–298.

Dawuda, M. M., Boateng, P. Y., Hemeng, O. B., & Nyarko, G. (2011). Growth and yield response of carrot (*Daucus carota* L.) to different rates of soil amendments and spacing. *Journal of Science and Technology,* 31(2), 11–20.

Elad, Y., Cytryn, E., Harel, Y. M., Lew, B., & Graber, E. R. (2011). The biochar effect: Plant resistance to biotic stresses. *Phytopathologia Mediterranea*, 50(3), 335–349.

Hewezi, T. (2015). Cellular signaling pathways and posttranslational modifications mediated by nematode effector proteins. *Plant Physiology,* 169(2), 1018–1026.

Hewezi, T., & Baum, T. J. (2013). Manipulation of plant cells by cyst and root-knot nematode

effectors. Molecular Plant-Microbe Interactions, 26(1), 9–16.
Huffaker, A., Pearce, G., Veyrat, N., Erb, M., Turlings, T. C., Sartor, R., ... & Schmelz, E. A. (2013). Plant elicitor peptides are conserved signals regulating direct and indirect antiherbivore defense. Proceedings of the National Academy of Sciences, 110(14), 5707–5712.
Igalavithana, A. D., Ok, Y. S., Usman, A. R., Al-Wabel, M. I., Oleszczuk, P., & Lee, S. S. (2016). The effects of biochar amendment on soil fertility. *SSSA Special Publication*, 63, 123–144.
Jeffery, S., Verheijen, F. G., van der Velde, M., & Bastos, A. C. (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystems & Environment,* 144(1), 175–187.
Kim, E., Seo, Y., Kim, Y., Park, Y., & Kim YoungHo. (2017). Effects of soil textures on infectivity of root-knot nematodes on carrot. *The Plant Pathology Journal*, 33(1), 66–74.
Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C., & Crowley, D. (2011). Biochar effects on soil biota: A review. *Soil Biology and Biochemistry*, 43(9), 1812–1836.
Lima, P. G. (2021). Synthetic antimicrobial peptides: Characteristics, design, and potential as alternative molecules to overcome microbial resistance. *Life Sciences*, 278, 119647.
Molinari, S. (2011). Natural genetic and induced plant resistance as a control strategy to plant-parasitic nematodes alternative to pesticides. *Plant Cell Reports*, 30(3), 311–323.
Novak, J. M., Busscher, W. J., Laird, D. L., Ahmedna, M., Watts, D. W., & Niandou, M. A. (2009). Impact of biochar amendment on fertility of a southeastern coastal plain soil. *Soil Science*, 174(2), 105–112.
Novotny, E. H., Hayes, M. H., Madari, B. E., Bonagamba, T. J., Azevedo, E. R. D., Souza, A. A. D. & Mangrich, A. S. (2009). Lessons from the Terra Preta de Índios of the Amazon region for the utilisation of charcoal for soil amendment. *Journal of the Brazilian Chemical Society,* 20(6), 1003–1010.
Olabiyi, T. I., & Oyedunmade, E. E. A. (2008). Efficacy of Furadan (Carbofuran) in control of root-knot nematode (Meloidogyne incognita) in hybrid yam varieties in southwestern Nigeria. American-Eurasian Journal of Scientific Research, 3(1), 67–71.
Sahebani, N., & Hadavi, N. (2008). Biological control of the root-knot nematode Meloidogyne javanica by Trichoderma harzianum. *Soil Biology and Biochemistry,* 40(8), 2016–2020.
Sikora, R. A., Greco, N., & Silva, J. F. V. (2005). Plant parasitic nematodes in subtropical and tropical agriculture (2nd ed.). *CABI Publishing.*
Vanzolini, T., Bruschi, M., Rinaldi, A. C., Magnani, M., & Fraternale, A. (2022). Multitalented synthetic antimicrobial peptides and their antibacterial, antifungal and antiviral mechanisms. *International Journal of Molecular Sciences*, 23(10), 5450.