Journal of Agriculture and Ecology Research International

23(2): 46-53, 2022; Article no.JAERI.85369
ISSN: 2394-1073

Plant Immunity and Potential of Plant Extracts in Management of Parasitic Nematodes

Milca Banda Medison [a], Rudoviko Galileya Medison [b*], Jingrong Hu [b] and Yi Zhou [b*]

[a] Research Center of Crop Stress Resistance Technologies, College of Agriculture, Yangtze University, 266, Jingmi Road, Jingzhou City, Hubei, 434025, China.
[b] Department of Plant Protection, College of Agriculture, Yangtze University, 266, Jingmi Road, Jingzhou City, Hubei, 434025, China.

Authors' contributions

This work was carried out in collaboration among all authors. Authors YZ and RGM conceived and designed the manuscript. Authors MBM and RGM wrote the manuscript and performed bibliographic search. Authors MBM and JH performed critical reading of the manuscript together. Authors JH and MBM edited the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAERI/2022/v23i230219

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/85369

Mini-review Article

Received 17 January 2022
Accepted 24 March 2022
Published 25 March 2022

ABSTRACT

One major challenge that agricultural production faces is the presence of plant-parasitic nematodes in crop fields. Plant-parasitic nematodes cause serious plant physical injuries, the inability of plants to acquire nutrients from the soil, and weaken the plant immune system. However, plants respond in several ways by producing hormones, anti-nematocidal proteins, repellents, nemastatic compounds, or inhibiting the feeding cell formation and development that minimize attack and injuries by the nematodes. Sometimes these mechanisms fail and therefore plant growers have to use plant management practices to prevent and suppress the presence of parasitic nematodes. The development and use of synthetic nematicides have limitations associated with costs and environmental pollution. Therefore, the use of plant extracts that contains anthelmintic compounds has proved to be successful in suppressing parasitic nematodes while maintaining environmental safety for living organisms. However, the relationship between plant immunity and the applications of plant extracts has not been well documented. It is against this background that this minireview explains the mechanism of plant immunity and the potential of plant extracts in enhancing plants to resist and suppress parasitic nematodes. The research progress and challenges of using the plant extracts have also been discussed thus creating potential areas of future research on applications

**Corresponding author: E-mail: mrodoviko@gmail.com, zhouyi@yangtzeu.edu.cn;*

of plant extracts in parasitic nematodes management. Furthermore, this minireview has recommended the use of sustainable integrated management of plant-parasitic nematodes approach.

Keywords: Allelochemicals; plant immunity; plant extracts; phytohormones; integrated parasite management.

1. INTRODUCTION

Plants are sessile organisms often exposed to attack by a wide variety of pathogens and insects which have a seriously devastating impact on plant growth and yield performance [1]. This threatens food security since plant defense again the pathogenic attack is done at the expense of plant growth and development.

Plant-parasitic nematodes (PPN) are one of the common parasites that cause serious yield reduction in plants because they disturb the transport system, divert plant nutrients, increase secondary infections and also act as vectors for viruses [2]. Plant yield loss due to PPN attack has been estimated at a range of 10 to 25% globally [3]. Approximately, a total of four thousand species of PNN have been identified of which most of them feed on roots [2] and most devastating is a root-knot nematode of *Meloidogyne* spp. [2,4]. On the other hand, In rice fields, *Hirschmanniella* spp. infected 58% of rice fields resulting in 25% yield losses [3,5]. As a result, various management practices have been implemented to optimize the management of plant-parasitic nematodes [6]. One common method is the use of synthetic nematicides which is being criticized because of its environmental unsuitability. Therefore, cheap, safe and sustainable management strategies need to be devised in place of synthetic chemicals. This minireview aims to highlight the current knowledge of the mechanisms that plants use to minimize nematodes attack and the potential of plant extracts and the reasons for their incorporation in the integrated management of plant-parasitic nematodes. Furthermore, the research progress and challenges associated with the application of the plant extracts with nematocidal activities have been highlighted.

2. MAJOR MECHANISMS OF PLANTS TO OVERCOME PARASITIC NEMATODES

2.1 Physical Barriers

Plant-parasitic nematodes must penetrate the cell wall of plants to feed. However, plants have physical mechanisms for defense against parasites, pests, and pathogens [7]. For example, roots have specialized structural cells that form endodermis and provide special protection against cyst and root-knot nematodes [8]. Plants also produce lignin with the aid of β-aminobutyric acid (BABA), thiamine, and sclareol within the roots that act against plant-parasitic nematodes [9]. However, the presence of a specific physical barrier in a plant is species-specific. Other plants have more nematode barriers than others. This gives the seasons for the proper management practices that would help to minimize the occurrence of parasitic nematodes in the plants.

2.2 Phytohormones

The plant-parasitic nematodes attack has resulted in the evolution of plant defense mechanisms related to plant hormones. Therefore, plant hormones are used by plants as a strategy against plant-parasitic nematodes. Ethylene (ET), jasmonate (JA), and salicylic acid (SA) are the major plant hormones that play a significant role in increasing plant defense against plant pathogens [10,11]. During plant attacks with root-knot nematodes, JA and ET play a key role in inducing various plant defense mechanisms [5]. The accumulation of JA, SA, and ET result in overexpression of pathogenesis-related genes (PR) like PR1,2 and 3 in different plant tissues [10,12] which result in increased immune responses against nematodes. In rice plants, for example, JA pathways have been reported to increase defense against plant-parasitic nematodes like *Meloidogyne graminicola*, *Ditylenchus angustus,* and *Hirschmanniella oryza*e [5,13]. In addition to SA, ET, and JA, other plant hormones like Auxin, GA, and ABA also have crucial functions in plant resistance against plant-parasitic nematodes [14].

Other studies reported that jasmonate acid in soybean defends against the cyst of nematode *Heterodera schachtii* [15]. A study done by Nahar et al., (2012) showed that plants treated with Me-jasmonate and ethephon (ethylene analog) were more resistant against rice root-knot nematodes *Meloidogyne graminicola* compared with untreated plants. Three nematodes that are *Heterodera schachrii*, *Meloidogyne javanica,* and

Pratylenchus neglectus, were applied to *Spinacia oleracea* in which the concentration of phytoecdysteroid, 20-hydroxyecdysone (20E) hormone was elevated to investigate the effects of 20E on plant-parasitic nematodes. Phytoecdysteroid was found to protect spinach from plant-parasitic nematodes because abnormal molting, reduced invasion, immobility, impaired development, and death of nematodes were observed in the plants with a high concentration of 20E. [16]. Based on these research studies, the role of hormones in inducing plant resistance and suppression of plant parasitic nematodes cannot be underestimated.

2.3 Allelochemicals

Plants that are aromatic, produce antagonistic compounds and toxins against plant-parasitic nematodes. These plants and their residues exhibit nematocidal properties [17–20]. Plant biosynthesizes various secondary metabolites that are different in their biological activities and mode of actions although closely related compounds may share similar biosynthetic pathways while other metabolites have diverse biosynthetic pathways [21]. Plant allelochemicals are one of the major mechanisms which plants use in their defense against enemies [7,22]. Allelochemical influences the interaction between plants and other organisms below and above ground [23]. By now approximately 100,000 secondary metabolites have been identified to be produced by plants of which just a small number of these metabolites have been described as allelochemicals that aid in plant defense mechanisms. These include those chemicals with nitrogen such as cyanogenic glycosides, non-protein amino acids, and benzoixazinods. Other allelochemicals of importance are terpenoids, alkaloids, and hydroxamic acids of benzoxazinoids and phenolic compounds (flavonoids quinones, phenolics, and coumarins) [1,23–25]. Plants with the ability to produce allelochemicals have been incorporated into the integrated pest and disease management as part of the cultural intercropping approach. The use of allelopathic *Ageratum conyzoide* plant has widely been used in South China to control weeds and soil pathogens. Usually, the plant secretes allelochemicals (agaratochromene and flavones) and volatile signaling compounds such as E-β-farnesene and α-bisabolene into the soils and air, respectively. These chemicals act on weeds and soil pathogens and predatory mites in citrus orchards [23,26,27]. Therefore, the use of plant extracts with nematocidal effects provides the alternative for synthetic chemical nematicides that renders environmental unproductivity and pollution. It is against this background that the use of botanicals with nematocidal value be incorporated in the management of plant-parasitic nematodes.

Other plant defense systems which plants use to overcome parasitic nematodes have been summarized in Fig. 1. These include the production of repellents, nematicides, proteins, nemastatic compounds, inhibition of feeding cell formation and development, and inhibiting the movement of plant-parasitic nematodes.

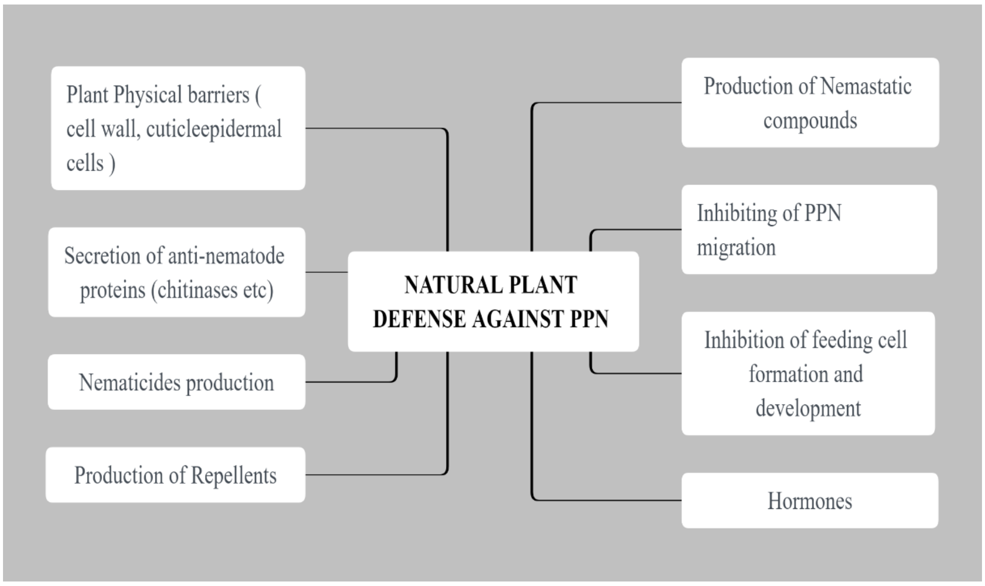

Fig. 1. A schematic summary of plant mechanisms against plant parasitic nematodes

3. MAJOR PROGRESS ON APPLICATIONS OF PLANT EXTRACTS

Research shows that plants produce approximately 200,000 volatile organic compounds [1] that exhibit various functions within a plant or to the external environment. Some of these compounds can only have paralyzing effects on nematodes, while others cause the death of nematodes [1]. For example, root metabolites have chemical compounds that act as nematode attractants, repellents, or hatching stimulants of inhibitors [28].

To control *Meloidogyne incognita* nematodes, a study was conducted to evaluate the effect of plant volatile organic compounds produced by *Brassica juncea*, *Azadirachta indica*, *Canavalia ensiformis*, *Mucuna pruriens,* and *Cajanus cajan.* The results found out that volatile organic compounds of extracts from *Azadirachta indica* and *Brassica juncea* crops were effective at restricting nematode second stage juveniles' movement, reduced gall formation, and reproduction. Among the mechanisms for volatile organic compounds, nematocidal activities were detected by the presence of alcohols, esters, and sulfur-containing compounds especially isothiocyanates [29]. Da Silva et al., [20] found that extracts from *Cymbopogon nardus* L. *Piper nigrum* L., *Brassica oleracea* L., and *Bertholletia excelsa* Bonpl were able to decrease second-stage juveniles' mobility completely and reduced egg hatching by the nematodes up to 47% compared with the control treatment. The results indicated the presence of volatile organic compounds in the extract that was toxic to eggs and second-stage juveniles, which are crucial development stages of root-knot nematode.

Another research investigated the nematocidal activity of three mint species aqueous extracts against root-knot *Meloidogyne inconita.* After conducting phytochemical analysis, the results showed the abundance of terpenes such as menthone, menthol, isomenthione, carvone, chlorogenic acid, rosmaric acid, salvianolic acid B, and luteolin-7-O-rutinoside that had high nematocidal activities against the root-knot nematode [30]. Furthermore, Julio Carlos P. Silva et al., [18] assessed volatile organic compounds in vitro and biofumigants produced from macerates of broccoli shoots and sunflower seed. The research found out that volatile organic compounds from sunflower seed caused more deaths of the second-stage juveniles, and both extracts were found to reduce the reproduction, galls formed, eggs produced, immobility of second-stage juveniles, and infectivity of root-knot nematodes. Chemical analysis found that the extracts had alcohols, sulfurated volatile organic compounds, and terpenes that were toxic to root-knot nematode *Meloidogyne inconita.* These are just few examples of application and efficacy of plant extracts in management of plant parasitic nematodes. However, there are several studies that have been done and several other are underway to find the best alternative for the synthetic nematicides [31,32].

4. INDUSTRIAL FORMULATIONS OF PLANT EXTRACT FOR PPN MANAGEMENT

In search of bioactive compounds with nematocidal components, various industrial formulations of plant extracts from a wide range of plants have been evaluated for their efficiency in managing plant-parasitic nematodes [17]. For instance, an oil extract from the Thyme plant has been used to make Promax which is used as a protective and curative soil fungicide and nematicide for controlling nematodes and soil-borne diseases. This marked another milestone in ensuring safety regarding the control of plant-parasitic nematodes and the physical and economic damage that they cause to crops and the whole environment [33].

The need to use less toxic and environmentally acceptable alternatives for commercial chemical synthetic nematicides is opening up new opportunities to explore the use of bio-rational products that are botanicals and nematocidal active [17]. Soil organic amendments help to control plant-parasitic nematodes and soil-borne diseases, improving soil physical and chemical properties and restricting the use of synthetic nematicides [34]. These soil amendments include compost manure, animal and green manure, nematocidal plants, and proteinoids wastes [35] and can release allelochemicals that are of high importance to suppress plant-parasitic nematodes. Various mechanisms displayed by the soil amendments of organic in nature include generation of nematocidal compounds such as ammonia and fatty acids during degradation, changes in soil physiology that are unsuitable for nematode behavior, increase in plant tolerance and resistance; and release of pre-existing nematocidal compounds in soil amendments [35]. Other plants secrete organic compounds while growing thus rendering the soil environment unsuitable for plant-parasitic nematodes. For example use of neem products and pyrethroids have been characterized as the more effective botanical source of natural oils, pheromones, and volatiles that act as mechanisms to suppress the presence of plant pests, pathogens, and plant-parasitic nematodes [36,37].

5. CHALLENGES AND OPPORTUNITIES

The use of volatile organic compounds has been reported to have phytotoxic in some studies. For example, volatile organic compounds produced by *salvia leucophylla* reduced cell elongation and cell division in radicals and hypocotyl of a germinating *Cucumis sativus*. In addition, volatile organic compounds also inhibited the growth of soil bacteria [38] that are crucial in plant growth and development. In another study, the decomposition of residues and dead leaves releases fourteen volatile organic compounds into the soil water around *Eucalyptus urophylla*. The volatile organic compounds constitute 1,8-cineole and terpinene-4-ol that inhibited the germination of cereal seeds [39]. Research conducted by Ogura et al., [40] shows that bio-compounds that were secreted by P. *expansum* completely inhibited the germination of Brassicaceae. Based on these research studies, it is necessary that thorough investigation need be conducted before using microbes, botanicals, and any bioproducts so that the intended purpose has been achieved. This provides a major research opportunity to explore various bio compounds that would otherwise enhance the use of plant extracts in the sustainable management of plant-parasitic nematodes.

While plant hormones are very crucial to plant immunity, some cyst nematodes and root-knot nematodes need auxins and cytokinin for the formation of feeding sites and secrete chorismite mutase into the plant that decreases proteinase inhibitors and other jasmonate-induced defense molecules [41,42]. Furthermore, analysis of whole genomes of most of the plant-parasitic nematodes has found parasitism genes that are responsible for the presence of proteins that mimic plant hormones [43]. This makes plant-parasitic nematodes suppress plant defense and parasitize the plant. However, the availability of other hormones, plant metabolites, and induced systemic resistance strength surpass the strength of nematodes pathogenicity in many plants.

Plant extracts are of high value in protecting plants against PPN and that plant metabolites and hormone production enhance the plant resistance against PPN. Therefore, this background provides a need to do further research on major plant extracts and the potential molecular mechanisms responsible for the accumulation of hormones and other biological compounds to further our understanding the on role each of them plays in enhancing plant immunity and suppression of plant parasitic nematodes.

6. CONCLUSION

So far, several management practices have been implemented to minimize plant parasitic nematodes impact on food and economic losses. Some of these ways have been underutilized including the use of plant extracts in the management of plant-parasitic nematodes. Therefore, this minireview is of significance to enhance our understanding on plant immunity in relationship with plant extracts and plant parasitic nematodes. This review would also help researchers and plant growers to maximize the use of plant extracts in the management of plant-parasitic nematodes thereby increasing environmentally friendly agriculture. However, no method is superior to completely eliminate plant parasitic nematode. Therefore, to enhance the plant resistance, and minimize the damage caused by the parasitic nematodes in plants, there is a need for more research on various prevention and control methods. The minireview is also recommending that various prevention and control methods be incorporated together, a method known as the sustainable integrated management of plant-parasitic nematodes.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Desmedt W, Mangelinckx S, Kyndt T, Vanholme B. A Phytochemical Perspective on Plant Defense Against Nematodes. Front Plant Sci. 2020;11. Available:https://doi.org/10.3389/fpls.2020.602079
2. Nicol JM, Turner SJ, Coyne DL, et al. Genomics and Molecular Genetics of Plant-Nematode Interactions. Genomics Mol Genet Plant-Nematode Interact; 2011. Available:https://doi.org/10.1007/978-94-007-0434-3
3. Luc M, Sikora RA, Bridge J. Plant parasitic nematodes in subtropical and tropical agriculture: Second Edition; 2005.
4. Fuller VL, Lilley CJ, Urwin PE. Nematode resistance. New Phytol. 2008;180:27–44. Available:https://doi.org/10.1111/j.1469-8137.2008.02508.x
5. Nahar K, Kyndt T, Nzogela YB, Gheysen G. Abscisic acid interacts antagonistically with classical defense pathways in rice-migratory nematode interaction. New Phytol. 2012;196:901–913. Available:https://doi.org/10.1111/j.1469-8137.2012.04310.x
6. Abd-Elgawad MMM, Askary TH. Fungal and bacterial nematicides in integrated nematode management strategies. Egypt J Biol Pest Control. 2018;28. Available:https://doi.org/10.1186/s41938-018-0080-x
7. Bernards MA. Plant natural products : A primer REVIEW / SYNTHE Plant natural products : a primer 1; 2015. Available:https://doi.org/10.1139/Z10-035
8. Holbein J, Franke RB, Marhavý P, et al. Root endodermal barrier system contributes to defence against plant-parasitic cyst and root-knot nematodes. Plant J. 2019;100:221–236. Available:https://doi.org/10.1111/tpj.14459
9. Sato K, Kadota Y, Shirasu K. Plant Immune Responses to Parasitic Nematodes. Front Plant Sci. 2019;10:1–14. Available:https://doi.org/10.3389/fpls.2019.01165
10. Bari R, Jones JDG. Role of plant hormones in plant defence responses. Plant Mol Biol. 2009; 69:473–488. Available:https://doi.org/10.1007/s11103-008-9435-0
11. Xie J, Yang F, Xu X, et al. Salicylic Acid, Jasmonate, and Ethylene Contribute to Rice Defense Against White Tip Nematodes Aphelenchoides besseyi. Front Plant Sci. 2022;12. Available:https://doi.org/10.3389/fpls.2021.755802
12. López MA, Bannenberg G, Castresana C. Controlling hormone signaling is a plant and pathogen challenge for growth and survival. Curr Opin Plant Biol. 2008;11:420–427. Available:https://doi.org/10.1016/j.pbi.2008.05.002
13. Khanam S, Bauters L, Singh RR, et al. Mechanisms of resistance in the rice cultivar Manikpukha to the rice stem nematode Ditylenchus angustus; 2018.
14. Glazebrook J. Contrasting mechanisms of defense against biotrophic and necrotrophic pathogens. Annu Rev Phytopathol. 2005;43:205–227. Available:https://doi.org/10.1146/annurev.phyto.43.040204.135923
15. Kammerhofer N, Egger B, Dobrev P, et al. Systemic above- and belowground cross talk: Hormone-based responses triggered by Heterodera schachtii and shoot herbivores in Arabidopsis thaliana. J Exp Bot. 2015;66:7005–7017. Available:https://doi.org/10.1093/jxb/erv398
16. Soriano IR, Riley IT, Potter MJ, Bowers WS. Phytoecdysteroids: A novel defense against plant-parasitic nematodes. J Chem Ecol. 2014;30:1885–1899. Available:https://doi.org/10.1023/B:JOEC.0000045584.56515.11
17. Ntalli NG, Caboni P. Botanical Nematicides : A Review; 2012.
18. Silva JCP, Campos VP, Barros AF, et al. Plant Volatiles Reduce the Viability of the Root-Knot Nematode Meloidogyne incognita Either Directly or When Retained in Water. Plant Dis. 2018; 102:2170–2179. Available:https://doi.org/10.1094/pdis-01-18-0143-re
19. Avato P, Laquale S, Argentieri MP, et al. Nematicidal activity of essential oils from aromatic plants of Morocco. J Pest Sci. 2017;90:711–722. Available:https://doi.org/10.1007/s10340-016-0805-0
20. Da Silva JCP, Campos VP, Barros AF, et al. Performance of volatiles emitted from different plant species against juveniles and eggs of Meloidogyne incognita. Crop Prot. 2019;116:196–203.

Available:https://doi.org/10.1016/j.cropro.2018.11.006
21. Neilson EH, Goodger JQD, Woodrow IE, Møller BL. Plant chemical defense : at what cost ? Trends Plant Sci. 2013;1–9. Available:https://doi.org/10.1016/j.tplants.2013.01.001
22. Latif S, Chiapusio G, Weston LA. Allelopathy and the Role of Allelochemicals in Plant Defence. Elsevier Ltd; 2017.
23. Kong CH, Xuan TD, Khanh TD, et al. Allelochemicals and Signaling Chemicals in Plants. Molecules. 2019;24:1–19. Available:https://doi.org/10.3390/molecules24152737
24. Afendi FM, Okada T, Yamazaki M, et al. KNApSAcK Family Databases : Integrated Metabolite – Plant Species Databases for Multifaceted Plant Research Special Issue – Databases. 2012;53:1–12. Available:https://doi.org/10.1093/pcp/pcr165
25. Ahuja I, Kissen R, Bones AM. Phytoalexins in defense against pathogens. Trends Plant Sci. 2012;17:73–90. Available:https://doi.org/10.1016/j.tplants.2011.11.002
26. Kong C, Hu F, Xu X, et al. Volatile allelochemicals in the Ageratum conyzoides intercropped citrus orchard and their effects on mites Amblyseius newsami and Panonychus citri. J Chem Ecol. 2005;31:2193–2203. Available:https://doi.org/10.1007/s10886-005-6085-4
27. Kong C, Liang W, Hu F, et al. Allelochemicals and their transformations in the Ageratum conyzoides intercropped citrus orchard soils. Plant Soil. 2004;264:149–157. Available:https://doi.org/10.1023/B:PLSO.0000047759.65133.fa
28. Sikder MM, Vestergård M. Impacts of Root Metabolites on Soil Nematodes. Front Plant Sci. 2020;10:1–18. Available:https://doi.org/10.3389/fpls.2019.01792
29. Barros AF, Campos VP, da Silva JCP, et al. Nematicidal activity of volatile organic compounds emitted by Brassica juncea, Azadirachta indica, Canavalia ensiformis, Mucuna pruriens and Cajanus cajan against Meloidogyne incognita. Appl Soil Ecol. 2014;80:34–43. Available:https://doi.org/10.1016/j.apsoil.2014.02.011
30. Caboni P, Saba M, Tocco G, et al. Nematicidal activity of mint aqueous extracts against the root-knot nematode Meloidogyne incognita. J Agric Food Chem. 2013;61:9784–9788. Available:https://doi.org/10.1021/jf403684h
31. Tiwari S, Pandey S, Singh Chauhan P, Pandey R. Biocontrol agents in co-inoculation manages root knot nematode [Meloidogyne incognita (Kofoid & White) Chitwood] and enhances essential oil content in Ocimum basilicum L. Ind Crops Prod. 2017;97:292–301. Available:https://doi.org/10.1016/j.indcrop.2016.12.030
32. Jones JG, Kleczewski NM, Desaeger J, et al. Evaluation of nematicides for southern root-knot nematode management in lima bean. Crop Prot. 2017;96:151–157. Available:https://doi.org/10.1016/j.cropro.2017.02.015
33. Mcgrath MT. Biopesticides for Managing Diseases of Leafy Vegetables Organically. 1994;5–8.
34. Gong B, Bloszies S, Li X, et al. Scientia Horticulturae Efficacy of garlic straw application against root-knot nematodes on tomato. Sci Hortic (Amsterdam). 2013;161:49–57. Available:https://doi.org/10.1016/j.scienta.2013.06.027
35. Oka Y. Mechanisms of nematode suppression by organic soil amendments — A Review. 2010;44:101–115. Available:https://doi.org/10.1016/j.apsoil.2009.11.003
36. Isman MB. R Epellents In M Odern A Griculture and; 2014. Available:https://doi.org/10.1146/annurev.ento.51.110104.151146
37. Regnault-roger C, Philogène BJR, Regnault-roger C, Philog BJR. Past and Current Prospects for the Use of Botanicals and Plant Allelochemicals in Integrated Pest Management Past and Current Prospects for the Use of Botanicals and Plant Allelochemicals in Integrated Pest Management *. 2008;0209. Available:https://doi.org/10.1080/13880200701729794
38. Muller WH. Volatile Materials Produced by Salvia leucophylla: Effects on Seedling Growth and Soil Bacteria. Bot Gaz. 1965;126:195–200. Available:https://doi.org/10.1086/336319

39. He H, Song Q, Wang Y, Yu S. Phytotoxic effects of volatile organic compounds in soil water taken from a Eucalyptus urophylla plantation. Plant Soil. 2014;377:203–215. Available:https://doi.org/10.1007/s11104-013-1989-1
40. Ogura T, Sunairi M, Nakajima M. 2-Methylisoborneol and Geosmin, the Main Sources of Soil Odor, Inhibit the Germination of Brassicaceae Seeds. Soil Sci Plant Nutr. 2000;46:217–227. Available:https://doi.org/10.1080/00380768.2000.10408777
41. Siddique S, Grundler FM. Parasitic nematodes manipulate plant development to establish feeding sites. Curr Opin Microbiol. 2018;46:102–108. Available:https://doi.org/10.1016/j.mib.2018.09.004
42. Gheysen G, Mitchum MG. Phytoparasitic nematode control of plant hormone pathways. Plant Physiol. 2019;179:1212–1226. Available:https://doi.org/10.1104/pp.18.01067
43. Bird DMK, Jones JT, Opperman CH, et al. Signatures of adaptation to plant parasitism in nematode genomes. Parasitology. 2015;142:S71–S84. Available:https://doi.org/10.1017/S0031182013002163

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/85369