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REVIEW ARTICLE

The mechanistic pathways of *Pochonia chlamydosporia*: A biology perspective on Nematode suppression and plant promotion

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Abstract

Pochonia chlamydosporia is a promising nematophagous fungus known for its multifaceted role in the biological suppression of plant parasitic nematodes and the enhancement of plant health. This review provides a mechanistic perspective on its functional biology, systematically dissecting the pathways through which *P. chlamydosporia* establishes in the rhizosphere, parasitizes nematode eggs, produces bioactive metabolites and triggers systemic defense responses in host plants. The fungus exhibits robust colonization strategies both in soil and plant roots, driven by factors like inoculum density and environmental conditions. It secretes enzymes and forms specialized structures for nematode egg parasitism, while also synthesizing metabolites with nematicidal and plant-growth-promoting properties. Moreover, its endophytic interaction with host plants modulates signaling pathways, triggering systemic defense gene expression. Through its diverse mechanistic actions, *P. chlamydosporia* emerges as a powerful bioagent contributing to both nematode management and improved plant growth.

Keywords: biocontrol efficacy; endophytic nature; plant defense mechanism; Plant growth promotion; *Pochonia chlamydosporia;* secondary metabolite

Abbreviations

PPN - Plant parasitic nematodes; PCN - Potato cyst nematode; BCA - Biocontrol agents; spp. - Species; ETL - Economic threshold level; PGP - Plant growth promotion; HPR - Host plant resistance; HPR - Host plant resistance; C - Celsius; cm - Centimetre; PCC - Presumed carrying capacity CPCR- Competitive polymerase chain reaction; LOX - Lipoxygenase; PIN II - Proteinase inhibitor II; PAL - Phenylalanine ammonia-lyase; PR1- Pathogenesis -related protein

Introduction

Plant parasitic nematodes (PPNs) are a major concern in agriculture, leading to significant economic losses worldwide due to their detrimental effects on plant health. Their widespread distribution and ability to infest numerous crops make them a silent but formidable adversary. Estimates suggest annual losses ranging from $80 billion to $157 billion due to PPNs (1). Many different phytoparasitic nematodes represent a danger to a variety of vegetables and field crops across the world, but the most significant ones are sedentary endoparasitic nematodes from the genera *Meloidogyne*, *Globodera* and *Heterodera* (2-5). In comparison to other PPN, the root-knot nematodes (*Meloidogyne* spp.) and the cyst nematodes (*Heterodera* spp. & *Globodera* spp.) were thought to be covert foes for crops. Due to their rapid reproduction, short life cycle, broad host range and endoparasitic nature, these soil pathogens are challenging to handle (6, 7).

Various management approaches, including cultural, physical, chemical and biological treatments, are used to control the nematode infestation at the economic threshold level (ETL). To achieve long-term nematode control, a variety of techniques were used (8). Chemical and biological control strategies were mostly preferred. Growers have therefore focused primarily on the use of chemicals for managing nematodes, which causes several issues, such as pesticide resistance, adverse impacts on human health, depletion of beneficial microorganisms, entry of lingering harmful substances in the food chain and reduced diversity of macro and microorganisms (9, 10). In response to several issues, more work is being done to create environmentally benign microbe-based pesticides or bio

pesticides that employ biocontrol agent (BCA) functions in a distinct manner as an active component than conventional chemical nematicides (10, 11).

The term biocontrol is defined as a decrease in nematode populations achieved by the action of living species other than the nematode-resistant host plant, which happens naturally or through the modification of the environment or the introduction of antagonists (12). In order to manage PPNs, a few nematophagous bacteria and fungi are commercially available (13). Among biocontrol agents, fungi have sophisticated techniques for entangling nematodes in both constricting and non-constricting rings, adhesive branches and can also kill them by secreting poisonous chemicals and digest their bodies by colonizing their female reproductive processes (14). The genera, such as *Paecilomyces*, *Verticillium*, *Purpureocillium*, *Arthrobotrys*, *Acremonium*, *Clonostachys*, *Chaetomium*, *Fusarium*, *Isaria*, *Penicillium*, *Phyllosticta* and *Trichoderma,* were reported to be nematophagous and hostile to nematodes (15, 16).

Nematophagous fungi, widely studied as natural enemies of nematodes, occur naturally in soil and function as either saprophytic or parasitic agents (17, 18). The potential of nematophagous fungi to control PPNs has been documented by several authors (19-21). Nevertheless, there are only a limited number of commercial products accessible for managing Meloidogyne spp. (19, 22-24). Among these nematophagous fungi, *P. chlamydosporia* is a promising candidate as a biocontrol agent (25-27) from the Clavicipitaceae family within the order Hypocreales. The genus Verticilium chlamydosporium was revised as *P. chlamydosporia* by (28). This fungus was reported to parasitize eggs and females of important species of PPNs like root-knot nematode, *Meloidogyne spp.* and cyst nematode like *Globodera spp.* and *Heterodera spp.* (29, 30). The mechanism of action of *P. chlamydosporia* was explored by Swarnakumari and Kalaiarasan (31). Complex tri-tropic interaction between plant-fungus-nematode was investigated for efficient application of *P. chlamydosporia* as a biopesticide within an integrated pest control strategy (32).

Pochonia chlamydosporia has been utilized for nematode management in essential crops for food security (Table 1). *Pochonia chlamydosporia* is used in the biological control of animal parasitic nematodes (33) and has demonstrated infectivity towards laboratory insect hemiptera (34).

Table 1. *Pochonia chlamydosporia* for control of nematodes in key crop species

Crop	Reference
Rice	(86)
Tomato	(87)
Potato	(88)
Cucumber	(63)
Banana	(89)
Soybean	(90)
Root beet	(91)

Entry and Establishment in the Rhizosphere

Colonization in soil

Research indicates that colonization and growth of *P. chlamydosporia* in soil (35-38). Abundant growth was observed when *P. chlamydosporia* was inoculated in the soil as only hyphal fragments and chlamydospores without any food base, then applied as colonized sand bran (Fig. 1). The population of *M. arenaria* was reduced >80 % due to *P. chlamydosporia* on tomato under glasshouse (35). Some isolates proliferated and survived for at least 3 months in significant numbers in soil. When the fungus was applied in the soil before planting, it resulted in long-term survival of the fungus as well as control of nematodes (27). The growth of *P. chlamydosporia* was more in peaty soil than in the loamy sand and sandy soil. The control of *M. incognita* on tomato was more in peaty sand (59 %) than in loamy sand (51 %) and sandy soil (39 %). The fungus survived in potted tomato plants for about 8 weeks (39). Efficient percolation and proliferation of *P. chlamydosporia* in both sandy and clayey soil up to 50 cm depth when it was applied through seed dressing against *M. incognita* population (40).

The saprophytic proliferation of *P. chlamydosporia* was abundant in the sterilized (γ-radiated) soil than in the field soil because of less competition from other soil microorganisms. At least 3 weeks are required for the fungus to reach the presumed carrying capacity (PCC) in soil. The increased growth of fungus in the potato cyst nematode (PCN) infested plant rhizosphere was found through competitive PCR (CPCR) after 14 weeks (41). *Pochonia chlamydosporia* growth in soil was less and the chlamydospore was the most important survival stage for the establishment of *P. chlamydosporia* in soil, has been emphazised by (42). Increased application of chlamydospores as inoculum

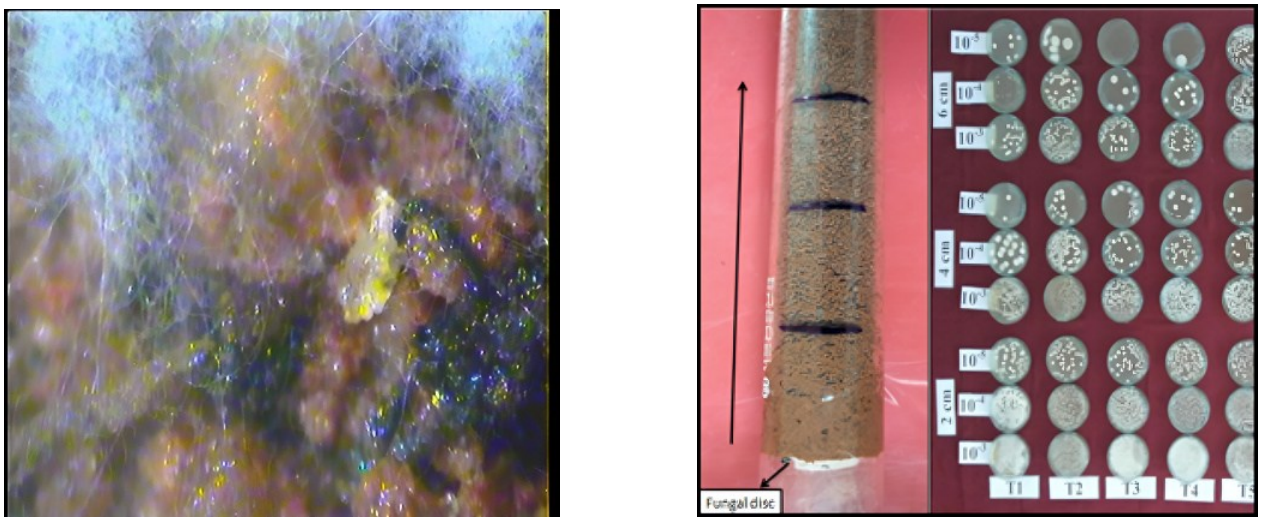

Fig. 1. Colonization of *P. chlamydosporia* in soil.

resulted in 10-fold increased density of *P. chlamydosporia* in the soil and there was no relationship between density of the fungus and parasitized eggs (43).

Pochonia chlamydosporia was able to establish within the first 2-3 weeks in the soil, increased in the number of colonies seen in the next 6-7 weeks, whereas 8-10 weeks after, growth marginally reduced and consistent growth was observed at the 12thweek (44). Mountain soil, red laterite and alluvial soil are conducive environments for the growth and establishment of *P. chlamydosporia*. Mountain soil was better in terms of parasitisation of egg mass and multiplication of spores due to the prevalence of lower pH and high organic carbon in that soil for the proliferation of the fungus. Incorporation of *P. chlamydosporia* into the soil reduced the reproduction factor compared to the surface application in carrot beds, which also improved its quality and yield (36).

Colonization in the roots

The root colonization of *P. chlamydosporia* was recorded, in which the cell wall modification was induced in the epidermis, but it did not affect the growth of plants. Hyphae of the fungus penetrated and proliferated into the roots by means of appresoria formation and a hyphal network was formed in the epidermis and cortical cells of the root, which was documented through Scanning Electron Microscope (46). The colonization of *P. chlamydosporia* was minimal near the root cap but gradually intensified as the distance from the cap increased, resulting in the development of a sporadic network of hyphae. *Pochonia chlamydosporia* promotes the growth of tomato and lettuce and produces the maximum number of chlamydospores within 15 days.

The ability to colonize the root of both native and introduced isolates was similar and there is no significant difference in *P. chlamydosporia*. Colony-forming unit formed by the introduced isolate on tomato and cabbage under the growth chamber was higher in cm^{-2} of root surface (Table 2) (47, 48). But in the native isolate, colonization and recovery from the soil were higher under the tunnel house on tomato (49). *Pochonia chlamydosporia* was able to colonize weeds as well as cultivated crops (50). *Pochonia chlamydosporia* root colonization caused the metabolic changes in *M. javanica* roots, with a particular emphasis on the production of phenolic compounds and flavonoids and altered the expression of genes related to the defense system (51).

Colonization pattern rhizosphere

Impact of varying levels of *P. chlamydosporia* inoculum density on colonization in soil, root and nematode control was analysed that the growth of the fungus partially depended on initial inoculum density, had maximum influence over root colonization and nematode parasitism (52). Density of *P. chlamydosporia* colonization was greater in the rhizosphere compared to the surrounding soil (53, 54). In sterile conditions, there was a weak positive correlation between the fungal density on plant roots and the extent of hyphal growth on tomato through direct observation. *Pochonia chlamydosporia* fungal spores population in the soil and rhizosphere was higher in all the plants screened except velvet beans after 30 days of planting (55). The fungal spores were found significantly higher in the maize rhizosphere compared to others on 90 days after planting.

The fungus proliferated in the tomato rhizosphere even though rhizosphere colonization does not cause lesions on roots and does not affect plant growth. The rhizosphere colonization of the fungus *P. chlamydosporia* differed with various plant species. The extensive rhizosphere colonization was found in the Brassicaceae family crops, especially kale and cabbage (56). *Pochonia chlamydosporia* has a high ability to colonize the rhizosphere and the persistence was about 10 weeks in the tomato rhizosphere. Single or individual isolate treatment of *P. chlamydosporia* in soil resulted in improved *M. javanica* control on tomato (38, 57). The application of fungus before planting in the rhizosphere resulted in 50 % of infected eggs, 25 % reduction of multiplication and root galling by root knot nematode (58).

Factors Responsible for Colonization by *P. chlamydosporia*

The abiotic factors like temperature, pH and C:N ratio influence colonization of *P. chlamydosporia*. The colony-forming units of *P. chlamydosporia* are influenced by soil temperature, particularly when the temperature exceeds 30 °C colony counts were less (37). Optimum temperature for the growth and development of *P. chlamydosporia* was 24 °C and 25 °C and it produced about 3.5 and 5.2 × 10^6 chlamydospores per gram of colonized substrate (59). Optimum temperature and pH required for spore production of *P. chlamydosporia* were standardized by (60). Increased water content resulted in increased mycelial growth duration, time taken for sporulation and production cycle. There exists an inverse correlation between the production of spores and the initial moisture content. The optimum proportion of water added to the substrate was a 1:1 (v/w) ratio. The growth and sporulation of *P. chlamydosporia* are significantly influenced by the C:N ratio and pH level. At pH 3.7 and the C:N ratio 10:1 yielded the maximum yield, while at pH 6.8 and the C:N ratio 40:1 yielded the highest biomass (61). Highest egg parasitization observed with *P. chlamydosporia* was 30.99 % infestation at a C:N ratio of 5:100, while the lowest rate was 12.03 % at a C:N ratio of 10, 5 which was recorded by (62) in the yeast extract medium against the root knot nematode. The nitrogen was increased (0.5-100 mM) with the carbon at 10 mM, resulting in increased parasitisation of eggs. Organic amendments decomposed at different temperatures affect the colony-forming units of *P. chlamydosporia* and the cfu was higher in decomposed material than the non-decomposed material. Fungal spores were higher in the sawdust, which was composted at 15 °C and 20 °C compared to other composts (62).

Table 2. Classification of the host based on fungus growth and development

Fungal colonization (CFU/cm²) in the root	Quality of the host	Crops
Less than 100	Poor host	Beans, cabbage, crotalaria, kale, pigeon pea, potato, pumpkin and tomato
100 - 200	Moderate host	Chilli, sweet potato, cowpea, rye, tobacco and cotton
More than 200	Good host	Aubergine, okra, soybean, sorghum and wheat

Nematode Egg Parasitism Cascade

Research indicates the mode of action of *P. chlamydosporia* (31). Hyphae of fungus attached to the egg surface on the first day of inoculation of spores, appressoria were produced on the second day and eventually the observation of complete colonization of the eggs was recorded on the fourth day (63). The eggs have become condensed and growth was arrested at the gastrula stage (Table 3) (31).

An *in vitro* study was performed to assess the parasitic activity of 10 strains of *P. chlamydosporia* on eggs of the PCN, *Globodera pallida*. The observed levels of pathogenicity varied between 34 % and 49 %. Impulsive hatching occurs when isolates of *P. chlamydosporia* exhibit a strong tendency to parasitize immature eggs rather than those containing second-stage juveniles (64). The effectiveness of utilizing *P. chlamydosporia* in seed treatment against root knot nematode *Meloidogyne hapla* led to a significant reduction in *M. hapla* eggs observed during a greenhouse experiment by up to 95.6 % (65). Moreover, the subsequently grown tomato plant had a lower gall index (66). *Pochonia chlamydosporia* reduced the number of egg masses, juveniles and galls nearly 50 % on tomato roots when the inoculum was applied as chlamydospores in the soil under greenhouse conditions (67). The population density of *M. hapla* on tomato and *G. pallida* on potato was reduced by more than 50 % when the chlamydospores were applied in the soil under greenhouse conditions (68). The most effective concentration of *P. chlamydosporia* inoculum for effective management of root knot nematode was 5000 chlamydospores per gram of soil (69).

Secondary Metabolite Production Pathway

Two compounds, namely Phomalactone and Monorden from *P. chlamydosporia* have nematicidal activity and various biological activities. *Meloidogyne incognita* control was less through Phomalactone in comparison with Aldicarb (70). The new compounds, which were present in the culture broth of *P. chlamydosporia* var. *spinulospora,* were Pochoniolides A and B, which exhibited capabilities in scavenging hydroxyl radicals and quenching singlet oxygen (Table 4) (71-73). A secondary metabolite, 3,4,7-trimethyl-6,8-dioxo-7,8-dihydro-6H-isochromen -7-yl ester, synthesized by *P. chlamydosporia* was named as Chlamyphilone, which had significant insecticidal activity and also this azaphilone compound caused mortality of aphids within 3 days of exposure (74). *Pochonia chlamydosporia* was grown in potato dextrose broth and kept under incubation at a temperature of 28 °C. After incubation, the extract was separated from the fungal mycelial mass. Nuclear magnetic resonance spectroscopy was used to identify the ketamine component from the extract. When ketamine is applied *in vivo* and *in vitro*, it validates its efficacy as a nematicide in *P. chlamydosporia* (34).

Signal Transduction in Plant Defense

Roots fortified by *P. chlamydosporia* colonization wield a shield against invaders (75-78). Molecular research indicates that *P. chlamydosporia* could induce phenotypes related to plant defense, which include anatomical alterations and the synthesis of distinct metabolites (45). In the presence of biotic stress factors, the interaction between host plants and *P. chlamydosporia* leads to colonization of plant roots, triggering a systemic activation of defense genes (Fig. 2). This process is intricate yet functional (78, 79). The following genes related to defense were tracked in terms of expression: lipoxygenase (*LOX*), proteinase inhibitor II (*PIN II*), phenylalanine ammonia-lyase (*PAL*) and pathogenesis-related protein 1 (*PR1*). This was done after inoculating roots with *P. chlamydosporia* and subjecting plants to various sources of biotic stress. These genes were chosen because of their differential expression in tomato roots colonized by *P. chlamydosporia* (76). *Pochonia chlamydosporia* aided in boosting the plant defense response, which resulted in decreased nematode parasitism and increased phenolic compound levels. Indeed, there were also changes in the quantity of some particular phenolic chemicals. During fungal colonization, roots showed higher amounts of chlorogenic acid, correlating with diminished root parasitism (80). Research indicates that the phenomenon mirrors observations in soybean genotypes resistant to root knot nematode (81, 82). *Pochonia chlamydosporia* increased the expression of PI1, an inhibitor of serine protease belonging to the family of PR proteins (80). These proteins play a crucial role in enhancing plant defense mechanisms against *M. incognita* (83). Applying both *P. chlamydosporia* to the soil and plant defense activators like Benzothiadiazole/cis-jasmone as foliar sprays resulted in a reduced number of eggs per egg masses in *M. chitwoodi* than potato plants treated with cis-jasmone alone on potato. Rhizosphere colonization of *P. chlamydosporia* was poor. However, they are efficient parasites of nematode eggs (84, 85).

Conclusion

In the quest for sustainable nematode management strategies, *P. chlamydosporia* stands out as a promising ally. Through its adept colonization patterns and potent biocontrol efficacy against various plant-parasitic nematodes, this nematophagous fungus holds immense potential. Not only does it suppress nematode populations effectively, but its secretion of antinemic metabolites and stimulation of plant defence mechanisms further enhance its value. As we navigate the complexities of agricultural sustainability, harnessing the power of *P. chlamydosporia* could prove instrumental. With its multifaceted benefits, including endophytic capabilities, production of

Table 3. Infection process of *Pochonia chlamydosporia* on root knot nematode eggs

Days after inoculation (DAI)	Fungal infection process	Embryonic development
DAI 1	On the surface of egg attachment of fungal hyphae	Gastrula stage
DAI 2	Formation of peg	Gastrula stage
DAI 3	Egg cell penetration and mycelial growth	Condensation of egg contents
DAI 5	Complete colonization	An empty space formed between the egg wall and the internal content
DAI 7	Colonization of internal contents	Disintegration of the egg wall
DAI 10	Thick-walled chlamydospore formation	Dissolution of egg

Table 4. Secondary metabolites produced by *Pochonia chlamydosporia*

Metabolite name	Metabolite class	References
13-Chloro-5,6,9,14,16-pentahydroxy-3-methyl-3,4,5,6,9,10-hexahydro-1H-2-benzoxacyclotetradecine-1,11(12H)-dione		(92)
6,13-Dichloro-5,9,14,16-tetrahydroxy-3-methyl-3,4,5,6,9,10-hexahydro-1H-2-benzoxacyclotetradecine-1,11(12H)-dione		(92)
Hexahydromonorden		(92)
Radicicol or Monorden		(70, 92-94)
Monorden analogue-1		(94)
Monorden E		(94)
Pochoniolides A		(71)
Pochoniolides B		(71)
Pochonin A		(92)
Pochonin B		(92)
Pochonin C		(92)
Pochonin D		(92)
Pochonin E	Resorcylic acid lactones	(92, 94)
Pochonin F		(92, 94)
Pochonin G		(93)
Pochonin H		(93)
Pochonin I		(93)
Pochonin J		(93)
Pochonin K		(94)
Pochonin L		(94)
Pochonin M		(94)
Pochonin N		(94)
Pochonin O		(94)
Pochonin P		(94)
Monocillin I		(94)
Monocillin II glycoside		(92, 94)
Monocillin II		(92, 94)
Monocillin III		(92, 94)
Monocillin I		(94)
Pseurotin A	Alkaloid	(95)
Chamydophilone	Azaphilone	(74)
Ketamine	Cyclohexanone	(34)
Aurovertin D		(96, 97)
Aurovertin F		(96, 97)
Aurovertin E	Pyranones	(96, 97)
Aurovertin I		(96, 97)
Phomalactone		(70)

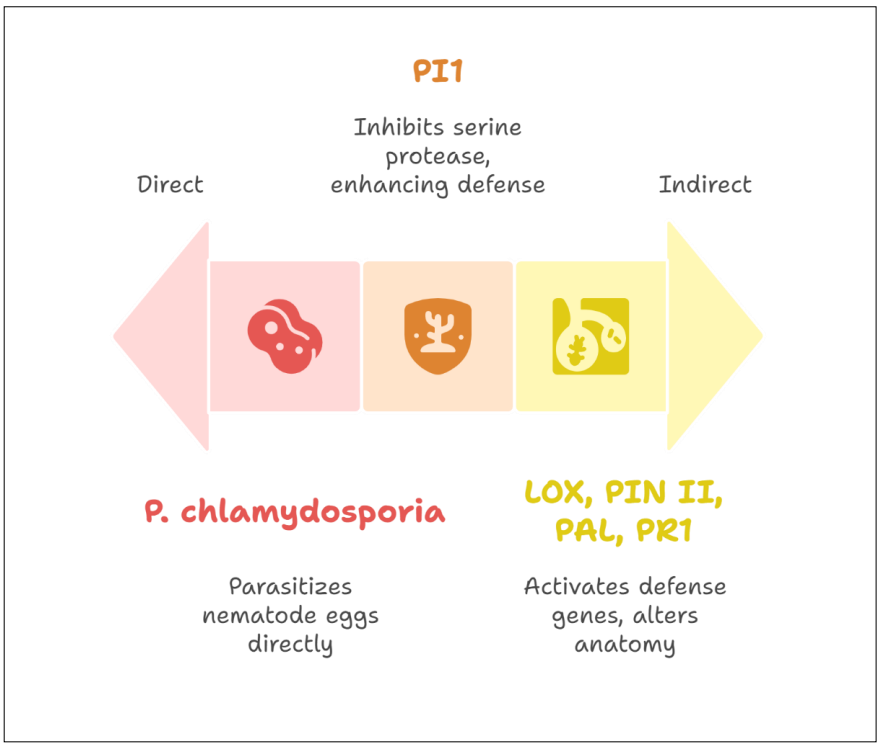

Fig. 2. Direct and indirect parasitism of *P. chlamydosporia*.

secondary metabolites and promotion of plant growth, *P. chlamydosporia* emerges as a beacon of hope in the fight against nematode-induced crop losses. Let's cultivate this alliance and pave the way for a greener, more resilient agricultural future.

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Authors' contributions

SB conceptualized the review structure, collected and reviewed the literature and wrote the initial draft of the manuscript. SN[1] supervised the overall development of the review, provided critical revisions and coordinated the final manuscript submission. AB contributed to the framing of the biological mechanisms and critically reviewed the content related to nematode suppression. TG contributed insights on fungal biology and reviewed the plant-pathogen interaction sections. SA reviewed entomological aspects and contributed to the biocontrol mechanism sections. SN[2] contributed to the molecular pathway insights and critically revised the bioinformatics and gene expression-related content. All authors read and approved the final manuscript. [SN[1] stands for Swarnakumari Narayanan and SN[2] stands for Saranya Nallusamy].

Compliance with ethical standards

Conflict of interest: The Authors do not have any conflict of interest to declare.

Ethical issues: None.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Grammarly in order to improve the language and readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

References

1. Ayaz M, Zhao J-T, Zhao W, Chi Y-K, Ali Q, Ali F, et al. Biocontrol of plant parasitic nematodes by bacteria and fungi: a multi-omics approach for the exploration of novel nematicides in sustainable agriculture. Front Microbiol. 2024;15:1433716. https://doi.org/10.3389/fmicb.2024.1433716
2. JN S. A world perspective on nematology: The role of the society. Vistas on nematology: A commemoration of the twenty-fifth anniversary of the society of nematologists. 1987;9.
3. Greco N, Di Vito M, Singh K, Saxena M. Effect of Heterodera ciceri on the growth of selected levels of cicer species. Nematologia Mediterranea. 1993;21(1):111–6.
4. Anwar SA, McKenry M. Incidence and population density of plant-parasitic nematodes infecting vegetable crops and associated yield losses in Punjab, Pakistan. Pak J Zool. 2012;44(2):327–33.
5. Singh R, Kumar U. Assessment of nematode distribution and yield losses in vegetable crops of Western Uttar Pradesh in India. Int J Sci Res. 2015;4(5):2812–6.
6. Trudgill DL, Blok VC. Apomictic, polyphagous root-knot nematodes: exceptionally successful and damaging biotrophic root pathogens. Annu Rev Phytopathol. 2001;39(1):53 –77. https://doi.org/10.1146/annurev.phyto.39.1.53
7. Manzanilla-López RH, Starr JL. Interactions with other pathogens. In: Starr JL, Manzanilla-López RH, editors. Root-knot nematodes. Wallingford UK: CABI; 2009. p. 223–45. https://doi.org/10.1079/9781845934927.0223
8. Whitehead A. Plant-parasitic nematodes: their importance and control. Plant nematode control. 1997:1-12.
9. Sindhu SS, Sehrawat A, Sharma R, Dahiya A. Biopesticides: use of rhizosphere bacteria for biological control of plant pathogens. Strain. 2016;90:166. https://doi.org/10.14429/dlsj.1.10747
10. Alizadeh M, Vasebi Y, Safaie N. Microbial antagonists against plant pathogens in Iran: A review. Open Agric. 2020;5(1):404–40. https://doi.org/10.1515/opag-2020-0031
11. Sindhu SS, Rakshiya YS, Sahu G. Biological control of soilborne plant pathogens with rhizosphere bacteria. Pest Technol. 2009;3 (1):10–21.
12. Stirling GR. Biological control of plant-parasitic nematodes. In: Stirling GR, editor. Diseases of nematodes. Boca Raton: CRC Press; 2018. p. 103–50. https://doi.org/10.1201/9781351071468-9
13. Abd-Elgawad M. Biological control agents of plant-parasitic nematodes. Egypt J Biol Pest Control. 2016;26(2):423–9.
14. Li J, Zou C, Xu J, Ji X, Niu X, Yang J, et al. Molecular mechanisms of nematode-nematophagous microbe interactions: basis for biological control of plant-parasitic nematodes. Annu Rev Phytopathol. 2015;53:67–95. https://doi.org/10.1146/annurev-phyto-080614-120336
15. Kassam R, Kamil D, Rao U. Caenorhabditis elegans as bait for isolating promising biocontrol fungi against Meloidogyne incognita from soils across India. Indian Phytopathol. 2021;74:739–52. https://doi.org/10.1007/s42360-021-00354-y
16. Murslain M, Javed N, Khan SA, Khan HU, Abbas H, Kamran M. Combined efficacy of Moringa oleifera leaves and a fungus, *Trichoderma harzianum* against Meloidogyne javanica on eggplant. Pak J Zool. 2014;46(3):827–32.
17. Araújo JV, Braga FR, Mendoza-de-Gives P, Paz-Silva A, Vilela VLR. Recent advances in the control of helminths of domestic animals by helminthophagous fungi. Parasitologia. 2021;1(3):168–76. https://doi.org/10.3390/parasitologia1030018
18. dos Santos Fonseca J, Altoé LSC, de Carvalho LM, de Freitas Soares FE, Braga FR, de Araújo JV. Nematophagous fungus Pochonia chlamydosporia to control parasitic diseases in animals. Appl Microbiol Biotechnol. 2023;107(12):3859–68. https://doi.org/10.1007/s00253-023-12525-0
19. Hallmann J, Davies KG, Sikora R. Biological control using microbial pathogens, endophytes and antagonists. In: Perry RN, Moens M, Starr JL, editors. Root-knot nematodes. Wallingford UK: CABI; 2009. p. 380–411. https://doi.org/10.1079/9781845934927.0380
20. Stirling GR. Biological control of plant-parasitic nematodes: soil ecosystem management in sustainable agriculture. Wallingford UK: CABI; 2014. https://doi.org/10.1079/9781780644158.0000
21. Peiris PUS, Li Y, Brown P, Xu C. Fungal biocontrol against Meloidogyne spp. in agricultural crops: A systematic review and meta-analysis. Biol Control. 2020;144:104235. https://doi.org/10.1016/j.biocontrol.2020.104235

22. Flores Francisco BG, Ponce IM, Plascencia Espinosa MÁ, Mendieta Moctezuma A, López y López VE. Advances in the biological control of phytoparasitic nematodes via the use of nematophagous fungi. World J Microbiol Biotechnol. 2021;37(10):180. https://doi.org/10.1007/s11274-021-03151-x

23. Darling E, Palmisano A, Chung H, Quintanilla-Tornel M. A new biological product shows promising control of the northern root-knot nematode, *Meloidogyne hapla*, in greenhouse tomatoes. J Nematol. 2023;55(1). https://doi.org/10.2478/jofnem-2023-0023

24. Wesemael W, Viaene N, Moens M. Root-knot nematodes (Meloidogyne spp.) in Europe. Nematology. 2011;13(1):3–16. https://doi.org/10.1163/138855410X526831

25. Manzanilla-López R, Esteves I, Powers S, Kerry B. Effects of crop plants on abundance of Pochonia chlamydosporia and other fungal parasites of root-knot and potato cyst nematodes. Ann Appl Biol. 2011;159(1):118–29. https://doi.org/10.1111/j.1744-7348.2011.00479.x

26. Tobin J, Haydock P, Hare M, Woods S, Crump D. Effect of the fungus Pochonia chlamydosporia and fosthiazate on the multiplication rate of potato cyst nematodes (*Globodera pallida* and *G. rostochiensis*) in potato crops grown under UK field conditions. Biol Control. 2008;46(2):194–201.

27. Kerry B, Kirkwood I, De Leij F, Barba J, Leijdens M, Brookes P. Growth and survival of *Verticillium chlamydosporium* Goddard, a parasite of nematodes, in soil. Biocontrol Sci Technol. 1993;3(3):355–65. https://doi.org/10.1080/09583159309355290

28. Zare R, Gams W, Evans H. A revision of Verticillium section Prostrata. V. The genus Pochonia, with notes on Rotiferophthora. Nova Hedwigia. 2001;73(1/2):51-86. https://doi.org/10.1127/nova.hedwigia/73/2001/51

29. Hidalgo-Diaz L, Bourne J, Kerry B, Rodríguez M. Nematophagous *Verticillium* spp. in soils infested with *Meloidogyne* spp. in Cuba: isolation and screening. Int J Pest Manage. 2000;46(4):277–84. https://doi.org/10.1080/09670870050206046

30. Kerry B, Crump D. Observations on fungal parasites of females and eggs of the cereal cyst-nematode, Heterodera avenae and other cyst nematodes. Nematologica. 1977;23(2):193-201. https://doi.org/10.1163/187529277x00543

31. Swarnakumari N, Kalaiarasan P. Mechanism of nematode infection by fungal antagonists, *Purpureocillium lilacinum* (Thom) Samson and *Pochonia chlamydosporia* (Goddard) Zare & Gams 2001. Pest Manag Hortic Ecosyst. 2017;23(2):165-9.

32. Escudero N, Marhuenda-Egea FC, Ibanco-Cañete R, Zavala-González EA, Lopez-Llorca LV. A metabolomic approach to study the rhizodeposition in the tritrophic interaction: tomato, Pochonia chlamydosporia and Meloidogyne javanica. Metabolomics. 2014;10:788-804. https://doi.org/10.1007/s11306-014-0632-3

33. Li S, Wang D, Gong J, Zhang Y. Individual and combined application of nematophagous fungi as biological control agents against gastrointestinal nematodes in domestic animals. Pathogens. 2022;11(2):172. https://doi.org/10.3390/pathogens11020172

34. Ferraz C, Soares F, Senna C, Silva L, Araujo J, Moreira T, et al. Interaction of the nematophagous fungus Pochonia chlamydosporia on eggs of *Spartocera dentiventris* (Berg)(Hemiptera: Coreidae) under laboratory conditions. Braz J Biol. 2020;81:1122-4. https://doi.org/10.1590/1519-6984.231550

35. De Leij FA, Kerry BR. The nematophagous fungus *Verticilium chlamydosporium* as a potential biological control agent for Meloidogyne arenaria. Revue Nematol. 1991;14(1):157-64.

36. Bontempo A, Fernandes R, Lopes J, Freitas L, Lopes E. Pochonia chlamydosporia controls Meloidogyne incognita on carrot. Australas Plant Pathol. 2014;43:421-4. https://doi.org/10.1016/j.apsoil.2019.103397

37. dos Santos MV, Esteves I, Kerry B, Abrantes I. Interactions between *Pochonia chlamydosporia* and *Meloidogyne chitwoodi* in a crop rotation scheme. Nematropica. 2014;44(1):37-46.

38. Xavier DM, Dallemole-Giaretta R, Freitas LGd, Lopes EA, Gardiano CG, Ferraz S. Combination of isolates of Pochonia chlamydosporia for the control of Meloidogyne javanica in tomato. Chil J Agr Anim Sci. 2017;33(1):24-7. https://doi.org/10.4067/S0719-38902017005000103

39. De Leij F, Kerry B, Dennehy J. Verticillium chlamydosporium as a biological control agent for Meloidogyne incognita and M. hapla in pot and micro-plot tests. Nematologica. 1993;39(1-4):115-26. https://doi.org/10.1163/187529293X00097

40. Nasu ÉdGC, Amora DX, Monteiro TSA, Alves PS, de Podestá GS, Ferreira FC, et al. Pochonia chlamydosporia applied via seed treatment for nematode control in two soil types. Crop Prot. 2018;114:106-12. https://doi.org/10.1016/j.cropro.2018.08.010

41. Mauchline T, Kerry B, Hirsch P. Quantification in soil and the rhizosphere of the nematophagous fungus Verticillium chlamydosporium by competitive PCR and comparison with selective plating. Appl Environ Microbiol. 2002;68(4):1846-53. https://doi.org/10.1128/AEM.68.4.1846-1853.2002

42. Kerry BR, Hirsch PR. Ecology of Pochonia chlamydosporia in the rhizosphere at the population, whole organism and molecular scales. In: Lopez-Llorca LV, Jansson HB, Maciá-Vicente JG, Duncan GH, editors. Biological control of plant-parasitic nematodes: Building coherence between microbial ecology and molecular mechanisms. Dordrecht: Springer; 2011. p. 171-82. https://doi.org/10.1007/978-1-4020-9648-8_7

43. Bourne J, Kerry B. Effect of the host plant on the efficacy of Verticillium chlamydosporium as a biological control agent of root-knot nematodes at different nematode densities and fungal application rates. Soil Biol Biochem. 1998;31(1):75-84. https://doi.org/10.1016/S0038-0717(98)00107-2

44. Nagesh M, Javeed S, Ramanujam B, Rangeswaran R. Suitability of soil types for Paecilomyces lilacinus and Pochonia chlamydosporia and their performance against root-knot nematode, Meloidogyne incognita on Lycopersicon esculentum in glasshouse. Indian J Agr Sci. 2013;83:826-30.

45. Lopez-Llorca L, Bordallo J, Salinas J, Monfort E, Lopez-Serna M. Use of light and scanning electron microscopy to examine colonisation of barley rhizosphere by the nematophagous fungus Verticillium chlamydosporium. Micron. 2002;33(1):61-7. https://doi.org/10.1016/S0968-4328(00)00070-6

46. Dallemole-Giaretta R, Freitas LGd, Lopes EA, Silva MdCSd, Kasuya MCM, Ferraz S. Pochonia chlamydosporia promotes the growth of tomato and lettuce plants. Acta Sci Agron. 2015;37:417-23. https://doi.org/10.4025/actasciagron.v37i4.25042

47. Hildalgo-Diaz L, Kerry B. Integration of biological control with other methods of nematode management. In: Ciancio A, Mukerji KG, editors. Integrated management and biocontrol of vegetable and grain crops nematodes. Dordrecht: Springer; 2008. p. 29-49. https://doi.org/10.1007/978-1-4020-6063-2_2

48. Manzanilla-Lopez RH, Esteves I, Finetti-Sialer MM, Hirsch PR, Ward E, Devonshire J, et al. Pochonia chlamydosporia: Advances and challenges to improve its performance as a biological control agent of sedentary endo-parasitic nematodes. J Nematol. 2013;45(1):1.

49. Sorribas F, Ornat C, Galeano M, Verdejo-Lucas S. Evaluation of a native and introduced isolate of Pochonia chlamydosporia against Meloidogyne javanica. Biocontrol Sci Technol. 2003;13(8):707-14. https://doi.org/10.1080/09583150310001606282

50. Bouchagier P. Survival of Root-Knot nematodes and their egg-parasitic fungus Pochonia chlamydosporia (Goddard) on weed roots. J Plant Sci. 2018;2(2):95-105. https://doi.org/10.25177/JPS.2.2.4

51. de Souza Gouveia A, Monteiro TSA, Luiz PHD, Balbino HM, de Magalhães FC, de Moura VAS, et al. The nematophagous root endophyte Pochonia chlamydosporia alters tomato metabolome. Rhizosphere. 2022;22:100531. https://doi.org/10.1016/j.rhisph.2022.100531

52. De Leij F, Dennehy J, Kerry B. The effect of fungal application rate and nematode density on the effectiveness of Verticillium chlamydosporium as a biological control agent for Meloidogyne incognita. Nematologica. 1992;38:112-22. https://doi.org/10.1163/187529292X00090

53. Bourne J, Kerry B, De Leij F. Methods for the study of Verticillium chlamydosporium in the rhizosphere. J Nematol. 1994;26(4S):587.

54. Zavala-Gonzalez EA, Escudero N, Lopez-Moya F, Aranda-Martinez A, Exposito A, Ricaño-Rodríguez J, et al. Some isolates of the nematophagous fungus Pochonia chlamydosporia promote root growth and reduce flowering time of tomato. Ann Appl Biol. 2015;166(3):472-83. https://doi.org/10.1111/aab.12199.

55. Luambano N, Kimenju J, Narla R, Waceke J. Colonisation of the Rhizosphere of plants which are poor host to root-knot nematodes by the biological agent Pochonia chlamydosporia. 2011.

56. Bourne JM, Kerry B, De Leij F. The importance of the host plant on the interaction between root-knot nematodes Meloidogyne spp. and the nematophagous fungus, Verticillium chlamydosporium Goddard. Biocontrol Sci Technol. 1996;6(4):539-48. https://doi.org/10.1080/09583159631172

57. Coutinho RR, Pacheco PVM, Monteiro TSA, Balbino HM, Moreira BC, de Freitas LG. Root colonization and growth promotion of cover crops by Pochonia chlamydosporia. Rhizosphere. 2021;20:100432. https://doi.org/10.1016/j.rhisph.2021.100432

58. Affokpon A, Coyne DL, De Proft M, Coosemans J. In vitro growth characterization and biocontrol potential of naturally occurring nematophagous fungi recovered from root-knot nematode infested vegetable fields in Benin. Int J Pest Manage. 2015;61(4):273-83. https://doi.org/10.1080/09670874.2015.1043971

59. Arevalo J, Hidalgo-Díaz L, Martins I, Souza JF, Castro JMC, Carneiro RMD, et al. Cultural and morphological characterization of Pochonia chlamydosporia and Lecanicillium psalliotae isolated from Meloidogyne mayaguensis eggs in Brazil. Trop Plant Pathol. 2009;34:158-63. https://doi.org/10.1590/S1982-56762009000300004

60. Nagesh M, Hussaini S, Ramanujam B, Rangeswaran R. Molecular identification, characterization, variability and infectivity of Indian isolates of the nematophagous fungus Pochonia chlamydosporia. Nematologia Mediterranea. 2007.

61. Mo M, Xu C, Zhang K. Effects of carbon and nitrogen sources, carbon -to-nitrogen ratio and initial pH on the growth of nematophagous fungus Pochonia chlamydosporia in liquid culture. Mycopathologia. 2005;159:381-7. https://doi.org/10.1007/s11046-004-5816-3

62. Luambano ND, Manzanilla-López RH, Kimenju JW, Powers SJ, Narla RD, Wanjohi WJ, et al. Effect of temperature, pH, carbon and nitrogen ratios on the parasitic activity of Pochonia chlamydosporia on Meloidogyne incognita. Biol Control. 2015;80:23-9. https://doi.org/10.1016/j.biocontrol.2014.09.003

63. Swarnakumari N, Sindhu R, Thiribhuvanamala G, Rajaswaminathan V. Evaluation of oil dispersion formulation of nematophagus fungus, *Pochonia chlamydosporia* against root-knot nematode, Meloidogyne incognita in cucumber. J Asia-Pac Entomol. 2020;23 (4):1283-7. https://doi.org/10.1016/j.aspen.2020.10.008

64. Vieira Dos Santos MC, Horta J, Moura L, Pires D, Conceicao I, Abrantes I, et al. An integrative approach for the selection of *Pochonia chlamydosporia* isolates for biocontrol of potato cyst and root knot nematodes. Phytopathol Mediterr. 2019;58(1):187-99. https://doi.org/10.14601/Phytopathol_Mediterr-23780

65. Uthoff J, Jakobs-Schönwandt D, Schmidt JH, Hallmann J, Dietz K-J, Patel A. Biological enhancement of the cover crop Phacelia tanacetifolia (Boraginaceae) with the nematophagous fungus Pochonia chlamydosporia to control the root-knot nematode Meloidogyne hapla in a succeeding tomato plant. BioControl. 2023;1-14. https://doi.org/10.1007/s10526-023-10222-5

66. Uthoff J, Jakobs-Schönwandt D, Dietz K-J, Patel A. Development of a seed treatment with pochonia chlamydosporia for biocontrol application. agriculture. 2024;14(1):138. https://doi.org/10.3390/agriculture14010138

67. Yang JI, Loffredo A, Borneman J, Becker JO. Biocontrol efficacy among strains of Pochonia chlamydosporia obtained from a root-knot nematode suppressive soil. J Nematol. 2012;44(1):67.

68. Siddiqui I, Atkins S, Kerry B. Relationship between saprotrophic growth in soil of different biotypes of Pochonia chlamydosporia and the infection of nematode eggs. Ann Appl Biol. 2009;155(1):131-41. https://doi.org/10.1111/j.1744-7348.2009.00328.x

69. Hidalgo-Díaz L, Franco-Navarro F, Grassi de Freitas L. Pochonia chlamydosporia microbial products to manage plant-parasitic Nematodes: Case Studies from Cuba, Mexico and Brazil. In: Manzanilla-López RH, Lopez-Llorca LV, editors. Perspectives in sustainable nematode management through Pochonia chlamydosporia applications for root and rhizosphere health. Cham: Springer; 2017. p. 311-42. https://doi.org/10.1007/978-3-319-59224-4_15

70. Khambay BPS, Bourne JM, Cameron S, Kerry BR, Zaki MJ. A nematicidal metabolite from *Verticillium chlamydosporium*. Pest Manag Sci. 2000;56(12):1098-9. https://doi.org/10.1002/1526-4998(200012)56:12<1098::AID-PS244>3.0.CO;2-H

71. Miyano R, Matsuo H, Nonaka K, Mokudai T, Niwano Y, Shiomi K, et al. Pochoniolides A and B, new antioxidants from the fungal strain *Pochonia chlamydosporia* var. *spinulospora* FKI-7537. J Biosci Bioeng. 2018;126(5):661-6. https://doi.org/10.1016/j.jbiosc.2018.05.003

72. Manzanilla-López RH, Lopez-Llorca LV. Perspectives in sustainable nematode management through *Pochonia chlamydosporia* applications for root and rhizosphere health. Cham: Springer; 2017. https://doi.org/10.1007/978-3-319-59224-4

73. Niu X-M. Secondary metabolites from Pochonia chlamydosporia and other species of Pochonia. In: Manzanilla-López RH, Lopez-Llorca LV, editors. Perspectives in sustainable nematode management through Pochonia chlamydosporia applications for root and rhizosphere health. Cham: Springer; 2017. p. 131-68. https://doi.org/10.1007/978-3-319-59224-4_7

74. Lacatena F, Marra R, Mazzei P, Piccolo A, Digilio MC, Giorgini M, et al. Chlamyphilone, a novel *Pochonia chlamydosporia* metabolite with insecticidal activity. Molecules. 2019;24(4):750. https://doi.org/10.3390/molecules24040750

75. Larriba E, Jaime MD, Nislow C, Martín-Nieto J, Lopez-Llorca LV. Endophytic colonization of barley (*Hordeum vulgare*) roots by the nematophagous fungus *Pochonia chlamydosporia* reveals plant growth promotion and a general defense and stress transcriptomic response. J Plant Res. 2015;128:665-78. https://doi.org/10.1007/s10265-015-0731-x

76. Pentimone I, Colagiero M, Ferrara M, Nigro F, Rosso LC, Ciancio A. Time-dependent effects of *Pochonia chlamydosporia* endophytism on gene expression profiles of colonized tomato roots. Appl Microbiol Biotechnol. 2019;103:8511-27. https://doi.org/10.1007/s00253-019-10058-z

77. Mingot-Ureta C, Lopez-Moya F, Lopez-Llorca LV. Isolates of the nematophagous fungus *Pochonia chlamydosporia* are endophytic in banana roots and promote plant growth. Agronomy. 2020;10 (9):1299. https://doi.org/10.3390/agronomy10091299

78. Tolba SR, Rosso LC, Pentimone I, Colagiero M, Moustafa MM, Elshawaf II, et al. Root endophytism by *Pochonia chlamydosporia* affects defense-gene expression in leaves of monocot and dicot hosts under multiple biotic interactions. Plants. 2021;10(4):718. https://doi.org/10.3390/plants10040718

79. Ghahremani Z, Escudero N, Saus E, Gabaldón T, Sorribas FJ. Pochonia chlamydosporia induces plant-dependent systemic resistance to *Meloidogyne incognita*. Front Plant Sci. 2019;10:945. https://doi.org/10.3389/fpls.2019.00945

80. de Souza Gouveia A, Monteiro TSA, Balbino HM, de Magalhães FC,

Ramos MES, Moura VAS, et al. Inoculation of *Pochonia chlamydosporia* triggers a defense response in tomato roots, affecting parasitism by Meloidogyne javanica. Microbiol Res. 2023;266:127242. https://doi.org/10.1016/j.micres.2022.127242

81. Rani CI, Muthuvel I, Veeraragavathatham D. Evaluation of 14 tomato genotypes for yield and root knot nematode resistance parameters. Pest Technol. 2009;3(1):76-80.

82. Ramzan M, Ahmed RZ, Khanum TA, Akram S, Jabeen S. Survey of root knot nematodes and RMi resistance to Meloidogyne incognita in soybean from Khyber Pakhtunkhwa, Pakistan. Eur J Plant Pathol. 2021;160:1-13. https://doi.org/10.1007/s10658-019-01740-z

83. Zinovieva S, Udalova ZV, Seiml-Buchinger V, Khasanov F. Gene expression of protease inhibitors in tomato plants with invasion by root-knot nematode *Meloidogyne incognita* and modulation of their activity with salicylic and jasmonic acids. Biol Bull. 2021;48:130-9. https://doi.org/10.1134/S1062359021440011

84. Santos MCVdAd. A challenge: biocontrol strategies for the management of potato cyst and rootknot nematodes [dissertation]. Coimbra: Universidade de Coimbra; 2013.

85. Vieira Dos Santos MC, Curtis RH, Abrantes I. The combined use of Pochonia chlamydosporia and plant defence activators - a potential sustainable control strategy for Meloidogyne chitwoodi. Phytopathol Mediterr. 2014:66-74. https://doi.org/10.14601/Phytopathol_Mediterr-12186

86. Khan M, Haque Z, Ahamad F, Zaidi B. Biomanagement of rice root-knot nematode Meloidogyne graminicola using five indigenous microbial isolates under pot and field trials. J Appl Microbiol. 2021;130(2):424-38. https://doi.org/10.1111/jam.14788

87. Escudero N, Lopez-Moya F, Ghahremani Z, Zavala-Gonzalez EA, Alaguero-Cordovilla A, Ros-Ibañez C, et al. Chitosan increases tomato root colonization by *Pochonia chlamydosporia* and their combination reduces root-knot nematode damage. Front Plant Sci. 2017;8:1415. https://doi.org/10.3389/fpls.2017.01415

88. Varandas R, Egas C, Conceicao IL. Potato cyst nematodes: New solutions to an old problem. Crop Prot. 2020;137:105303. https://doi.org/10.1016/j.cropro.2020.105303

89. Silva SD, Carneiro RM, Faria M, Souza DA, Monnerat RG, Lopes RB. Evaluation of Pochonia chlamydosporia and Purpureocillium lilacinum for suppression of *Meloidogyne enterolobii* on tomato and banana. J Nematol. 2017;49(1):77-85. https://doi.org/10.21307/jofnem-2017-047

90. Messa VR, da Costa ACT, Kuhn OJ, Stroze CT. Nematophagous and endomycorrhizal fungi in the control of Meloidogyne incognita in soybean. Rhizosphere. 2020;15:100222. https://doi.org/10.1016/j.rhisph.2020.100222

91. Haj Nuaima R, Ashrafi S, Maier W, Heuer H. Fungi isolated from cysts of the beet cyst nematode parasitized its eggs and counterbalanced root damages. J Pest Sci. 2021;94:563-72. https://doi.org/10.1007/s10340-020-01254-2

92. Hellwig V, Mayer-Bartschmid A, Müller H, Greif G, Kleymann G, Zitzmann W, et al. Pochonins A- F, new antiviral and antiparasitic resorcylic acid lactones from Pochonia chlamydosporia var. catenulata. J Nat Prod. 2003;66(6):829-37. https://doi.org/10.1021/np020556v

93. Shinonaga H, Kawamura Y, Ikeda A, Aoki M, Sakai N, Fujimoto N, et al. Pochonins K-P: new radicicol analogues from Pochonia chlamydosporia var. chlamydosporia and their WNT-5A expression inhibitory activities. Tetrahedron. 2009;65(17):3446-53. https://doi.org/10.1016/j.tet.2009.02.027

94. Shinonaga H, Kawamura Y, Ikeda A, Aoki M, Sakai N, Fujimoto N, et al. The search for a hair-growth stimulant: new radicicol analogues as WNT-5A expression inhibitors from Pochonia chlamydosporia var. chlamydosporia. Tetrahedron Lett. 2009;50(1):108-10. https://doi.org/10.1016/j.tetlet.2008.10.099

95. Bloch P, Tamm C, Bollinger P, Petcher TJ, Weber HP. Pseurotin, a new metabolite of Pseudeurotium ovalis STOLK having an unusual hetero-spirocyclic system.(Preliminary Communication). Helv Chim Acta. 1976;59(1):133-7. https://doi.org/10.1002/hlca.19760590114

96. Wang Y-l, Li L-f, Li D-x, Wang B, Zhang K, Niu X. Yellow pigment aurovertins mediate interactions between the pathogenic fungus Pochonia chlamydosporia and its nematode host. J Agric Food Chem. 2015;63(29):6577-87. https://doi.org/10.1021/acs.jafc.5b02596

97. Niu X-M, Wang Y-L, Chu Y-S, Xue H-X, Li N, Wei L-X, et al. Nematodetoxic aurovertin-type metabolites from a root-knot nematode parasitic fungus *Pochonia chlamydosporia*. J Agric Food Chem. 2010;58(2):828-34. https://doi.org/10.1021/jf903259n

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