Bioinputs for sustainable nematode management in Brazil: efficacy, challenges, and policy perspectives

Giovana Cândida Marques[1], Gustavo Ferreira Bellato[1], Bruna Rodrigues Moreira[2*], José Feliciano Bernardes Neto[1]

[1] Centro de Excelência em Bioinsumos (CEBIO), Instituto Federal de Educação, Ciência e Tecnologia Goiano, 88 Street, No. 310, St. Sul, 74085-010, Goiânia, GO, Brazil.
[2] Laboratório de Ficologia (LAFIC), Universidade Federal de Santa Catarina, Eng. Agrônomo Andrei Cristian Ferreira Street, 216, Carvoeira, 88040-535, Florianópolis, SC, Brazil.
** Corresponding author. E-mail: bruna.rm01@gmail.com*

ABSTRACT. The intensification of nematode-related losses in Brazilian agriculture has renewed interest in sustainable management strategies based on bioinputs. This systematic review (2018–2024) compiled 48 peer-reviewed studies from Scopus, Web of Science, SciELO, and the CAPES Journals Portal to evaluate the efficacy and limitations of microbial and botanical bioinputs against plant-parasitic nematodes. The main biological agents identified (*Trichoderma* spp., *Bacillus* spp., *Pochonia chlamydosporia*, and *Purpureocillium lilacinum*) act through parasitism, antibiosis, competition, and induction of systemic resistance, resulting in population suppression of *Meloidogyne*, *Pratylenchus*, and *Heterodera* species. Reported outcomes include up to 70% reduction in root-gall formation, improved root architecture, and 15–25% yield increases in tomato, soybean, and cotton. Nonetheless, field performance remains inconsistent due to environmental variability, formulation stability, and the need for more context-specific recommendations despite the recent expansion of product registration in Brazil. Evidence indicates that the integration of bioinputs with cultural and genetic tactics, such as crop rotation, resistant cultivars, and soil-health management, maximizes their efficiency. Under Brazil's National Bioinputs Program (Decree No. 10.375/2020) and the Bioinputs Law (Law No. 15.070/2024), scaling these technologies depends on formulation advances, context-specific protocols, and stronger extension services. Overall, bioinputs represent an effective and environmentally safe component of integrated nematode management, linking productivity gains with sustainability and soil conservation.

Key words: Bioinputs, nematodes, biological control, productivity, sustainability

DOI: https://doi.org/10.33837/msj.v9i1.1749

Received October 20th, 2025. Accepted March 13rd,2026. Published March 25th, 2026.
Associate editor: Anderson Rodrigo da Silva

INTRODUCTION

The exponential increase of plant-parasitic nematode populations in agricultural soils has become one of the major challenges of modern agriculture, given the severe root damage caused by these pathogens, which compromises plant development and substantially reduces yield. Climate change may exacerbate these losses by silencing plant resistance genes under heat stress, favoring the proliferation of nematodes and other pathogens. Species belonging to the genera *Meloidogyne*, *Pratylenchus*, *Heterodera*, *Helicotylenchus*, and *Aphelenchoides* are among the most economically important worldwide and are responsible for multibillion-dollar losses in crop and forestry systems (Jones et al. 2013; Sikora et al. 2018).

Eradication of nematodes from infested fields is unfeasible because of their high adaptability, survival mechanisms, and broad host range. The realistic goal is to reduce populations below the economic damage threshold through integrated, sustainable, and long-term management strategies (Timper, 2014; Coyne et al. 2018).

In Brazil, since the Green Revolution of the 1970s, the prevailing production model has been based on large-scale monocropping and intensive use of chemical inputs for pest and disease control (Vidal & Dias, 2023). Although effective in the short term, this model has caused serious environmental, sanitary, and economic impacts, including the emergence of pathogen populations with higher virulence due to selection pressure. As an alternative, bioinputs have emerged as promising components of Integrated Pest Management (IPM), particularly for biological control of plant-parasitic nematodes (Timper, 2014).

Bioinputs are products of biological origin: living microorganisms, microbial metabolites, plant extracts, or other natural compounds capable of acting directly or indirectly on target pests, promoting plant growth, or inducing resistance mechanisms that strengthen the plant's natural defenses (Brasil, 2020; Lei nº 15.070, 2024). In nematode management, the main microbial agents include bacteria of the genera *Bacillus* and *Pasteuria* and fungi such as *Trichoderma*, *Purpureocillium*, and *Pochonia*. These organisms act through multiple mechanisms (parasitism, competition, secretion of lytic enzymes, and induction of systemic resistance) affecting various nematode stages including eggs, juveniles, and adults (Timper, 2014; Sikora et al. 2018). In addition to reducing dependency on synthetic nematicides, biological agents help maintain soil microbiological balance, suppress other soilborne pathogens such as *Fusarium* spp., enhance root growth, and improve drought tolerance.

Family farming, which represents 77% of Brazilian rural establishments and employs about 67% of the agricultural labor force (IBGE, 2017), benefits particularly from bioinputs adoption, as it aligns with agroecological principles, production diversification, and farmer autonomy. However, smallholders are also among the most affected by nematode infestations due to limited technical assistance and restricted access to specialized research and extension services. Despite adopting conservative practices such as organic fertilization, biofertilizers, crop intercropping, and biological control, these measures alone are insufficient to suppress nematode populations under high-pressure conditions (Imfeld & Vuilleumier, 2012).

In this context, integrating bioinputs with cultural, genetic, and soil-health practices represents an effective and sustainable alternative to sole reliance on chemical nematicides. This approach aligns with Brazil's National Bioinput Program (Decree No. 10.375/2020) and is reinforced by the Bioinputs Law (Lei No. 15.070/2024), which establishes the legal and regulatory framework for production, commercialization, and use of bioinputs in agriculture. Despite growing interest in these technologies, there remains a knowledge gap regarding their systematic application to nematode management, particularly under tropical conditions.

Therefore, this review aims to provide an updated synthesis of bioinput-based strategies for managing plant-parasitic nematodes, highlighting mechanisms of action, efficacy, agronomic and environmental benefits, and contributions to a sustainable agriculture and emphasizing their potential to overcome the limitations of traditional agrochemical-based management.

MATERIAL AND METHODS

This study is a systematic literature review focused on the use of bioinputs for the management of plant-parasitic nematodes. The adopted methodology enabled a comprehensive description of the topic and a critical synthesis of the main scientific findings reported across different agricultural contexts.

The bibliographic search was conducted in the electronic databases Scopus, Web of Science, CAPES Journals Portal, and SciELO, using the following keywords and Boolean combinations: *"plant-parasitic nematodes," "biological control," "bioinputs," "sustainable agriculture," "Trichoderma," "Bacillus,"* and *"Pochonia chlamydosporia."* The selection of sources was carried out systematically through the screening of titles, abstracts, and keywords, prioritizing studies that addressed the subject in a broad and integrative manner. Inclusion criteria comprised peer-reviewed articles published between 2018 and 2024, in Portuguese, Spanish, or English, that were available in full text and presented empirical data related to nematode control through bioinputs. Review papers, editorials, and duplicate records were excluded; in the case of duplicated studies, only the most complete version was retained.

From an initial dataset of 2,069 retrieved studies, 48 publications met all inclusion criteria and were incorporated into the qualitative analysis. For each selected paper, data were extracted regarding the target nematode genera, type of bioinput (microbial or botanical), mechanisms of action, and reported agronomic outcomes. These parameters were compared and grouped into analytical categories to enable a structured and critical synthesis of the evidence available in the literature.

RESULTS AND DISCUSSION

Capacity of bioinputs to promote sustainable agriculture

Bioinputs, or biologically based agricultural inputs, are divided into different groups, such as biofertilizers, bioinsecticides, and biostimulants, each playing a fundamental role in promoting plant health and improving production efficiency. Multifunctional microorganisms have been recognized as effective plant growth promoters and technological tools that support the scalability of sustainable agriculture (Rezende et al. 2021). In the Brazilian context, publications from Embrapa emphasize the use of microorganisms or natural extracts to reduce reliance on synthetic inputs and mitigate environmental impacts (Meyer et al. 2022).

Among the main obstacles to the adoption of bioinputs are the lack of clear regulations, farmers' resistance to change, limited access to technical information, and high initial implementation costs. Overcoming these barriers requires coordinated actions by governments, research institutions, private companies, and agricultural organizations to raise awareness, provide technical training, and develop adequate regulatory frameworks (Silva Medina et al. 2024).

Suppression of plant-parasitic nematodes using bioinputs

With regard to plant-parasitic nematodes, although many technologies are under development, the scientific literature addressing the use of bioinputs specifically for nematode suppression is still limited. However, reviews on the role of beneficial microorganisms and natural extracts in agricultural sustainability suggest their applicability in nematode management as well (Rezende et al. 2021; Meyer et al. 2022). The integration of biological agents with cultural practices, such as crop rotation, the use of resistant cultivars, and soil-health management, has proven promising for enhancing the resilience and long-term sustainability of production systems.

The benefits of bioinputs in reducing nematode populations have been consistently demonstrated across crops and environments. The main mechanisms through which bioinputs suppress plant-parasitic nematodes are summarized in Table 1, including parasitism, antibiosis, competition, and systemic resistance induction.

Table 1. Main mechanisms of nematode suppression.

Type of action	Mechanism	Effect
Parasitism	Fungi such as *Purpureocillium lilacinum* parasitize nematode eggs and juveniles	Direct reduction of nematode populations
Antibiosis	Production of enzymes such as chitinases, proteases, or nematotoxic metabolites	Inhibition of nematode reproduction and survival
Competition	Occupation of rhizosphere niches that limit nematode establishment	Ecological suppression
Induction of systemic resistance	Bioinputs activate natural plant defense mechanisms	Roots become more resistant to nematode penetration

Source: adapted from Hussain et al. (2024).

Although the literature consistently reports positive results, control efficiency can vary, particularly when biological agents are applied without complementary practices such as crop rotation or organic fertilization. These differences indicate that biological control success depends on a locally adapted integrated-management strategy rather than a single, generalized approach (Niño-Arteaga et al. 2023).

Despite their promise, bioinputs still face technical challenges, including formulation stability, storage, and large-scale application. Many products exhibit reduced effectiveness under field conditions compared with controlled environments, which may frustrate growers and limit adoption (Santos & Oliveira, 2021). Moreover, although the number of registered microbiological products has increased in Brazil, field recommendations still require refinement according to edaphoclimatic conditions, production systems, and target nematode species.

In addition to formulation and operational constraints, the efficacy of bionematicides under field conditions is strongly influenced by environmental and edaphic factors. Soil temperature, moisture, pH, texture, organic matter content, and the composition of native microbial communities can directly affect the survival, establishment, colonization, and activity of introduced microorganisms in the rhizosphere. Agronomic factors such as crop management, application timing, compatibility with fertilizers and pesticides, and the level of nematode infestation also contribute to variable outcomes. Therefore, the performance of microbial bioinputs is context dependent and should be interpreted within an integrated management framework rather than as a universally stable standalone solution (Imfeld & Vuilleumier, 2012; Geisseler & Scow, 2014; Backer et al. 2018).

This technological development is also reflected in the regulatory expansion of microbiological products for nematode management in Brazil. According to the Agrofit database maintained by the Brazilian Ministry of Agriculture and Livestock (MAPA), 111 biological products were registered for the control of 11 plant-parasitic nematode species, with active registrations distributed among 36 companies. These products are based on 20 microorganism species, including 15 bacteria and 5 fungi, with a predominance of terrestrial applications, especially in furrow and seed treatment. Unlike most chemical nematicides, which are commonly registered for a specific crop-pathogen combination, microbiological products in Brazil are registered according to the target nematode, allowing broader use across different crops when the target species is included on the label. This regulatory feature expands their practical applicability and strengthens the strategic importance of bionematicides within integrated nematode management programs (Agrofit, 2025).

Under unmanaged conditions, plant-parasitic nematodes cause root-gall formation, reduced water and nutrient uptake, physiological stress, and yield losses that may reach 40 %, depending on the crop (Rajendran et al. 2024). When bioinputs suppress nematode pressure, benefits include improved root growth, reduced chemical-nematicide use, enhanced vegetative vigor, and higher yields (El-Marzoky et al. 2024). Table 2 compiles the principal microbial agents evaluated for nematode control in different crops, emphasizing the effectiveness of *Trichoderma*, *Pochonia*, *Purpureocillium*, and bacterial species such as *Bacillus* and *Pseudomonas*. In addition to microbial agents, plant extracts have also shown potential for nematode control, as summarized in Table 3.

Most reviewed studies were performed under laboratory or short-term conditions. Long-term trials assessing the persistence of bioinput effects across multiple crop cycles remain scarce, limiting extrapolation to large-scale conventional agriculture (Silva Medina et al. 2024).

The success of biological control is also linked to the technical training of farmers. Regions with continuous technical assistance and agroecological transition programs show higher adoption rates and effectiveness of bioinputs. This underscores the importance of rural-extension investment, continuous training, and public policies that promote technological dissemination (Niño-Arteaga et al. 2023).

Table 2. Biological agents used in the control of plant-parasitic nematodes.

Biological agent	Mode of action	Main target	Reported results
Trichoderma harzianum	Parasitism of eggs, enzyme and antibiotic production	*Meloidogyne incognita*	Up to 71% reduction in tomato infestation; improved root growth.
Pochonia chlamydosporia	Parasitism of eggs and juveniles	*M. javanica and Heterodera glycines*	Up to 65% control in carrot and soybean; moderate persistence in soil
Purpureocillium lilacinum	Penetration and destruction of eggs and larvae	*Meloidogyne spp., Pratylenchus spp.*	Up to 68% reduction in nematode populations in cotton
Bacillus subtilis	Production of metabolites, antibiosis, induction of systemic resistance	*Pratylenchus brachyurus, Rotylenchulus reniformis*	40% control in soybean; 18% increase in root dry mass
Paecilomyces fumosoroseus	Extracellular-enzyme production and competition	*Meloidogyne spp.*	50–60% average efficacy in greenhouse vegetables
Bacillus amyloliquefaciens	Antibiosis and resistance induction	*M. incognita, P. brachyurus*	30–45% control; enhanced plant vigour
Pseudomonas fluorescens	Siderophore production and egg-hatching inhibition	*R. reniformis*	Up to 53% reduction in cotton; variable field performance

Table 3. Examples of plant-derived bioinputs used for nematode management.

Plant source	Active compound	Effect
Neem (*Azadirachta indica*)	Azadirachtin	Inhibits egg hatching and feeding
Garlic (*Allium sativum*)	Allicin	Toxic to juveniles
White mustard (*Sinapis alba*) or forage radish (*Raphanus sativus*)	Glucosinolates (biofumigation)	Releases nematicide isothiocyanates
Sunn hemp (*Crotalaria* spp.)	Allelopathic compounds	Reduces nematode populations; non-host effect

Use of microorganisms in crops for the control of plant-parasitic nematodes

Several studies show that bioinputs can be effective against plant-parasitic nematodes, particularly in vegetables, soybean, and cotton. For example, *Trichoderma* spp. consistently suppresses *M. incognita* and promote growth in tomato under greenhouse conditions and in protected cultivation, via parasitism, mycoparasitism, antibiosis, and induced resistance (Imfeld & Vuilleumier, 2012; Guzmán-Guzmán et al. 2023). Likewise, *P. chlamydosporia* has repeatedly reduced egg masses and juveniles of root-knot and cyst nematodes and improved root health in horticultural systems (Polenovicz et al. 2023).

In soybean, *Trichoderma* isolates have controlled *P. brachyurus* and improved plant performance (Oliveira et al. 2021), and *Bacillus*-based products are reported as promising bioprotectants in on-farm trials and extension literature (Nascimento et al. 2022; Louro et al. 2024). In cotton, seed or soil treatments with *Trichoderma* and rhizobacteria have been associated with reduced *R. reniformis* pressure and yield benefits in field experiments (Timper, 2014).

Despite these advances, field efficacy varies markedly with temperature, moisture, soil type, crop management, and compatibility with agrochemicals. This variation is particularly relevant in tropical systems, where fluctuations in rainfall, soil temperature, and moisture regimes may alter microbial persistence and root-zone colonization. In addition, acidic soils, low organic matter, and antagonistic interactions with native microbiota may reduce the survival or competitiveness of introduced strains. For this reason, the same bioinput may produce distinct results across regions, seasons, and production systems, reinforcing the need for locally validated recommendations. Performance tends to be higher when bioinputs are integrated with cultural practices (e.g., crop rotation, cover crops, resistant cultivars) and when formulations favor rhizosphere colonization (Sosa-Gómez et al. 2022; Oliveira et al. 2021). Limitations frequently reported include short persistence in soil, batch-to-batch variability, and the need for repeated applications, factors that can raise costs for smallholders and argue for formulation improvement and integrated use (Sosa-Gómez et al. 2022; Oliveira et al. 2021).

While mineral fertilizers and pesticides have supported yield gains, intensive use can negatively affect soil microbiota. Long-term nitrogen inputs often acidify soils and shift microbial communities (Guo et al. 2010; Geisseler & Scow, 2014), and broad pesticide use can depress microbial diversity and function, with downstream effects on decomposition and nutrient cycling (Imfeld & Vuilleumier, 2012). These trade-offs reinforce the rationale for incorporating multifunctional microorganisms (e.g., PGPR and *Trichoderma*) that act through direct mechanisms as nutrient mobilization, phytohormone production, siderophore-mediated iron acquisition and indirect mechanisms such as pathogen suppression and induced resistance (Lopes et al. 2018; Backer et al. 2018; Huo et al. 2020; Guzmán-Guzmán et al. 2023). Systemic acquired resistance has also been documented as part of *Trichoderma*'s mode of action in crops, alongside VOC-mediated antagonism of *Sclerotinia sclerotiorum* in soybean systems (Pinho et al. 2020; Macena et al. 2020).

Coinoculation with nitrogen-fixing bacteria (e.g., *Rhizobium tropici*, *Azospirillum brasilense*) remains a complementary strategy in Brazilian legumes; trials by Embrapa report yield gains in common bean with appropriate inoculation and timing (Oliveira et al. 2021). Overall, solid field validation, better formulations, and integration with agronomic practices are key to achieving consistent bioinput performance in real-world production systems (Sosa-Gómez et al. 2022; Oliveira et al. 2021).

CONCLUSION

This review shows that bioinputs, particularly *Trichoderma* spp., *Bacillus* spp., *P. chlamydosporia*, and *P. lilacinum*, offer a robust, science-based alternative for suppressing plant-parasitic nematodes while promoting root growth, plant vigor, and, in many cases, yield gains. Their multi-mechanistic action (parasitism, antibiosis, competition, and induction of systemic resistance) and compatibility with soil-health practices make them central tools for integrated nematode management in tropical production systems.

At the same time, performance in open-field conditions remains heterogeneous. This heterogeneity is closely associated with environmental and management-related factors, including soil temperature, moisture, pH, texture, organic matter, native microbiota, and application conditions, which directly influence the persistence and efficacy of microbial agents. In parallel, the current Brazilian regulatory framework already includes a substantial number of registered biological products for nematode management, indicating that technological availability is advancing, although more context-specific recommendations are still needed to ensure consistent field performance. The main bottlenecks are formulation stability and persistence, batch-to-batch variability, context-dependent efficacy, and gaps in context-specific recommendations and field validation across different regions and production systems. Evidence across the studies reviewed indicates that bioinputs perform best when embedded in integrated programs that combine cultural tactics, host resistance, and careful compatibility with fertilizers and pesticides.

To convert potential into large-scale, durable impact, we recommend: (i) targeted selection of agents by crop–nematode complex; (ii) improved formulations and delivery systems suited to tropical soils; (iii) standardized, context-specific application protocols; (iv) monitoring of efficacy across seasons; and (v) coordinated investment in R&D, regulation, and extension. Under the current Brazilian policy environment (Decree No. 10.375/2020; Law No. 15.070/2024), qualified adoption of bioinputs can simultaneously reduce chemical dependency, enhance soil health, and strengthen productivity and resilience in family and commercial farming.

ACKNOWLEDGEMENTS

We thank the Instituto Federal Goiano (IF Goiano) and the Center of Excellence in Bioinputs (CEBIO) for institutional support and research infrastructure. We also acknowledge the administrative support provided by FUNAPE (Fundação de Apoio à Pesquisa) and the funding support from FAPEG (Fundação de Amparo à

Pesquisa do Estado de Goiás) and FAPESC (Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina- FAPESC N.º: 985/2025). The views and conclusions expressed in this article are those of the authors and do not necessarily represent the official positions of the supporting institutions.

REFERENCES

Backer, R., Rokem, J. S., & Ilangumaran, G. (2018). Plant growth-promoting rhizobacteria: Context, mechanisms of action, and roadmap to commercialization of biostimulants for sustainable agriculture. *Frontiers in Plant Science, 9*, 1473. DOI: https://doi.org/10.3389/fpls.2018.01473

Brasil. (2020). Decreto nº 10.375, de 26 de maio de 2020. Institui o Programa Nacional de Bioinsumos. *Diário Oficial da União*.

Brasil. (2024). Lei nº 15.070, de 23 de dezembro de 2024. Dispõe sobre a produção, registro e uso de bioinsumos. *Diário Oficial da União*. URL:https://www.planalto.gov.br/ccivil_03/_ato2023-2026/2024/lei/l15070.htm

Brasil. Ministério da Agricultura e Pecuária. (2025). AGROFIT – Sistema de agrotóxicos fitossanitários. URL: https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/insumos-agricolas/agrotoxicos/agrofit

Coyne, D. L., Nicol, J. M., & Claudius-Cole, A. O. (2018). *Practical plant nematology: A field and laboratory guide* (3rd ed.). CABI/IITA.

Du Preez, G., Daneel, M., De Goede, R., Du Toit, M. J., Ferris, H., & Fourie, H. (2022). Nematode-based indices in soil ecology: Application, utility and future directions. *Soil Biology and Biochemistry, 169*, 108640. DOI: https://doi.org/10.1016/j.soilbio.2022.108640

El-Marzoky, A. M., El-Sayed, A., & Hafez, M. (2024). Utilizing endophytic plant growth-promoting bacteria and the nematophagous fungus *Purpureocillium lilacinum* as biocontrol agents against *Meloidogyne incognita* on tomato plants. *European Journal of Plant Pathology*. DOI: https://doi.org/10.1007/s10658-024-02907-z

Geisseler, D., & Scow, K. M. (2014). Long-term effects of mineral fertilizers on soil microorganisms: A review. *Soil Biology and Biochemistry, 75*, 54–63. DOI: https://doi.org/10.1016/j.soilbio.2014.03.023

Guo, J. H., Liu, X. J., Zhang, Y., Shen, J. L., Han, W. X., Zhang, W. F., Christie, P., Goulding, K. W. T., Vitousek, P. M., & Zhang, F. S. (2010). Significant acidification in major Chinese croplands. *Science, 327*(5968), 1008–1010. DOI: https://doi.org/10.1126/science.1182570

Guzmán-Guzmán, P., Kumar, A., de los Santos-Villalobos, S., Parra-Cota, F. I., Orozco-Mosqueda, M. del C., Fadiji, A. E., Hyder, S., Babalola, O. O., & Santoyo, G. (2023). *Trichoderma* species: Our best fungal allies in the biocontrol of plant diseases – A review. *Plants, 12*(3), 432. DOI: https://doi.org/10.3390/plants12030432

Huo, Y., Kang, J. P., Ahn, J. C., Kim, Y. J., Piao, C. H., Yang, D. U., & Yang, D. C. (2020). Siderophore-producing rhizobacteria reduce heavy metal-induced oxidative stress in *Panax ginseng* Meyer. *Journal of Ginseng Research, 44*(6), 1226–1243. DOI: https://doi.org/10.1016/j.jgr.2019.12.008

Hussain, M., Xuan, P., Xin, Y., Ma, H., Zhou, Y., Wen, S., Hamid, M. I., Wan, T., Hu, J., Li, Y., Kang, S., Liu, X., & Xiang, M. (2024). Redundancy in microbiota-mediated suppression of the soybean cyst nematode. *Microbiome,* 12, 125. DOI: https://doi.org/10.1186/s40168-024-01840-x

IBGE. (2017). *Censo agropecuário 2017: Resultados definitivos*. Instituto Brasileiro de Geografia e Estatística.

Imfeld, G., & Vuilleumier, S. (2012). Measuring the effects of pesticides on bacterial communities in soil: A critical review. *European Journal of Soil Biology, 49*, 22–30. DOI: https://doi.org/10.1016/j.ejsobi.2011.11.010

Jones, J. T., Haegeman, A., Danchin, E. G. J., Gaur, H. S., Helder, J., Jones, M. G. K., Kikuchi, T., Manzanilla-López, R., Palomares-Rius, J. E., Wesemael, W. M. L., & Perry, R. N. (2013). Top 10 plant-parasitic nematodes in molecular plant pathology. *Molecular Plant Pathology, 14*(9), 946–961. DOI: https://doi.org/10.1111/mpp.12057

Lopes, R., Tsui, S., Gonçalves, P. J. R. O., & Queiroz, M. (2018). A look into a multifunctional toolbox: Endophytic *Bacillus* species provide broad and underexploited benefits for plants. *World Journal of Microbiology and Biotechnology, 34*(7), 94. DOI: https://doi.org/10.1007/s11274-018-2479-7

Louro, A., dos Santos, R., Ferreira, C. E., Silva, R., Carvalho, V., & de Sousa, T. P. (2024). Uso de *Bacillus subtilis* no incremento da produção na cultura da soja. *Cadernos de Agroecologia, 19*(1).

Macena, A. M. F., Kobori, N. N., Mascarin, G. M., Vida, J. B., & Hartman, G. L. (2020). Antagonism of *Trichoderma*-based biofungicides against *Sclerotinia sclerotiorum* and growth promotion of soybean. *BioControl, 65*(2), 235–246. DOI: https://doi.org/10.1007/s10526-019-09976-8

Meyer, M. C., Bueno, A. de F., Mazaro, S. M., & Silva, J. C. (Eds.). (2022). *Bioinsumos na cultura da soja*. Embrapa Soja.

Nascimento, V. C., Santos, K. C. R., Alencar, K. L. C., Castro, M. B., Krüger, R. H., & Lopes, F. A. C. (2022). *Trichoderma*: Biological control efficiency and perspectives for the Brazilian Midwest states and Tocantins. *Brazilian Journal of Biology, 82*, e260161. DOI: https://doi.org/10.1590/1519-6984.260161

Niño-Arteaga, D. M., Macías-López, B. C., Olivas-García, J. M., Alonso-Gómez, M. A., Sánchez, E., & Muñoz-Márquez, E.. (2023). Biocontrol of the root-knot nematode *Meloidogyne incognita* with *Purpureocillium lilacinum* and liquid bio-formulates in tomato. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 51*(1), 13010. DOI: https://doi.org/10.15835/nbha51113010

Oliveira, C. M., Almeida, N. O., Cortes, M. V. C. B., Lobo Júnior, M., Rocha, M. R., & Ulhoa, C. J. (2021). Biological control of *Pratylenchus brachyurus* with isolates of *Trichoderma* spp. on soybean. *Biological Control, 152*, 104412. DOI: https://doi.org/10.1016/j.biocontrol.2020.104425

Pinho, R. S. C., Pozzebon, B. C., Rodrigues, K. R. R., Arns, R. B., Alves, C. A., & Bergmann, R. (2020). Rhizobacteria in the control of *Sclerotinia sclerotiorum* and effects on soybean seedling development. *Colloquium Agrariae, 16*(4), 110–120. DOI: https://doi.org/10.5747/ca.2020.v16.n4.a388

Polenovicz, A., Krzyzanowski, A. A., & Silva, L. R. (2023). Control of nematodes in organic horticulture exploiting the multifunctional capacity of microorganisms. *Horticulturae, 9*(8), 920. DOI: https://doi.org/10.3390/horticulturae9080920

Rajendran, J., Dubey, J., Kumar, V., & Sujayanand, G. K. (2024). Nematode egg-parasitic fungus *Purpureocillium lilacinum*: Efficacy of indigenous strains for management of *Meloidogyne incognita* in chickpea. *Egyptian Journal of Biological Pest Control, 34*(4). DOI: https://doi.org/10.1186/s41938-024-00769-5

Rezende, C. C., Silva, M. A., Frasca, L. L. de M., Faria, D. R., Filippi, M. C. C. de, Lanna, A. C., & Nascente, A. S. (2021). Multifunctional microorganisms: Use in agriculture. *Research, Society and Development, 10*(2), 1–15. DOI: https://doi.org/10.33448/rsd-v10i2.12725

Santos, J. A., & Oliveira, M. R. (2021). *Manejo de pragas e doenças: A busca por formas sustentáveis de controle*. Editora Científica.

Sikora, R. A., Coyne, D. L., Hallmann, J., & Timper, P. (Eds.). (2018). *Plant-parasitic nematodes in subtropical and tropical agriculture* (3rd ed.). CABI. DOI: https://doi.org/10.1079/9780851997278.0000

Silva Medina, G., Rotondo, R., Rodríguez, G. R. (2024). Innovations in agricultural bioinputs: Commercial products developed in Argentina and Brazil. *Sustainability, 16*(7), 2763. DOI: https://doi.org/10.3390/su16072763

Sosa-Gómez, D. R., Santos, J. C. P., (2022). Bioinsumos na cultura da soja. *In* J. C. P. Santos, M. C. Meyer, A. F. Bueno, S. M. Mazaro, & J. C. da Silva (Eds.), *Tecnologias para a produção sustentável da soja* (pp. 457–472). Embrapa Soja.

Timper, P. (2014). Conserving and enhancing biological control of nematodes. *Journal of Nematology, 46*(2), 75–89.

Vidal, M. C., & Dias, R. P. (2023). Bioinsumos a partir das contribuições da agroecologia. *Revista Brasileira de Agroecologia, 18*(1), 171–192. DOI: https://doi.org/10.33240/rba.v18i1.23735

To cite this paper, use:

Marques, G.C., Bellato, G.F., Moreira, B.R., Bernardes Neto, J.F. (2026) Bioinputs for sustainable nematode management in Brazil: efficacy, challenges, and policy perspectives. *Multi-Science Journal* 9 (1), 11-17. DOI: https://doi.org/10.33837/msj.v9i1.1749