DOI: 10.54083/ResBio/8.1.2026/27-35

Res. Bio., 2026, 8(1):27-35

Research Biotica

e-ISSN: 2582-6743

January-March, 2026

Article ID: RB260

Review Article

Biocontrol Potential and Mechanistic Basis of *Bacillus velezensis* in the Management of Plant-Parasitic Nematodes (PPNs)

Siva M.[1*], Aditya Abhijeet Guha[1], Janani M.[2] and Pragadeesh A.R.U.[3]

[1]Dept. of Plant Pathology, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu (641 003), India
[2]Dept. of Nematology, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu (641 003), India
[3]Dept. of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu (641 003), India

Corresponding Author

Siva M.

✉: sivamuthamiz1997@gmail.com

Conflict of interests: The author has declared that no conflict of interest exists.

How to cite this article?

Siva, M., Guha, A.A., Janani, M., Pragadeesh, A.R.U., 2026. Biocontrol Potential and Mechanistic Basis of *Bacillus velezensis* in the Management of Plant-Parasitic Nematodes (PPNs). *Research Biotica* 8(1), 27-35. DOI: 10.54083/ResBio/8.1.2026/27-35.

Abstract

Plant-parasitic nematodes (PPNs) have emerged as a global threat to agriculture, resulting in severe crop losses. Previously, farmers relied on chemical nematicides for their control; however, their environmental and health risks have necessitated the search for sustainable and eco-friendly alternatives. *Bacillus velezensis* is a plant growth-promoting rhizobacterium (PGPR) that has emerged as a promising biocontrol agent due to its multifaceted antagonistic strategies. This review consolidates evidence on its mechanisms underlying its mode of action, such as nematicidal metabolites and induced systemic resistance (ISR), alongside progress in formulation and field performance. By outlining both current successes and critical research gaps, this review aims to guide the development of practical *B. velezensis*-based strategies for sustainable agriculture.

Keywords: *Bacillus velezensis*, Biocontrol, Induced systemic resistance (ISR), Plant-parasitic nematodes (PPNs), Secondary metabolites

Introduction

Plant-parasitic nematodes constitute one of the major constraints to global agricultural productivity. Out of the 3000 nematode species known to man, the most destructive ones include *Meloidogyne*, *Heterodera*, *Globodera* and *Radopholus*. These stand out because of their wide host range and their ability to cause serious and lasting damage (Jones *et al.*, 2013). Since most of these dwell beneath the soil surface, detecting them becomes a challenge, as their association with the plant becomes evident only when the plant succumbs to the nematode infestations, evidenced by visible symptoms and decline in plant production. On a global scale, it is estimated that these microscopic organisms can cause losses worth USD 150-175 billion, highlighting the urgency for sustainable and effective management solutions (Nicol *et al.*, 2011).

Historically, management of plant-parasitic nematodes relied primarily on synthetic nematicides, *viz.*, organophosphates, carbamates and fumigants like methyl bromide. But their widespread use was associated with significant environmental concerns. Due to the harmful impacts of these chemicals, they were banned post the declaration of the Montreal Protocol (Desaeger *et al.*, 2020). Although they killed the nematodes, they also poisoned other soil organisms and degraded too slowly (Nicol *et al.*, 2011; Desaeger *et al.*, 2020). This led to a shift towards a more sustainable and environmentally sound approach leading the researchers to adopt microbial biocontrol agents, which were eco-friendly, budget-friendly and biodegradable. In this regard, *Bacillus velezensis* has emerged as a valuable biocontrol agent for the management of nematodes. It can survive in diverse soil environments, effectively colonize root surfaces, produce biofilms and produce a cohort of antimicrobial metabolites (effective against the nematodes), thereby distinguishing it from other biocontrol agents (Rabbee *et al.*, 2023). Also, its ability to prime the plants' immunity through induced systemic resistance (ISR) makes the plants resistant against future nematode attacks and infections. This combination of nematicidal activity and indirect plant-mediated defence

Article History

RECEIVED on 03rd September 2025 RECEIVED in revised form 12th March 2026 ACCEPTED in final form 26th March 2026

development makes *B. velezensis* a potential candidate for managing nematodes sustainably (Vasantha-Srinivasan *et al.*, 2025).

B. velezensis has gained considerable attention as an effective plant growth-promoting rhizobacteria (PGPR), for the role it plays in sustainable agriculture, specifically in alleviating plant-parasitic nematodes (PPNs) (Yao *et al.*, 2025). Not only does it manage nematode population and boost plant immunity, but it also improves soil health. Direct antagonism, stimulation of host defence responses and modifications in the rhizosphere environment are the various complementary mechanisms mediating the nematicidal activity of *B. velezensis.* A key strategy is the production of antimicrobial metabolites (Ma *et al.*, 2025), which damage the cuticle of the nematodes and prevent their locomotion and reproduction, disrupting the nematode cuticles, impairing motility and interfering with reproductive processes (Figueiredo *et al.*, 2025).

Additionally, the bacterium *B. velezensis* primes the plant through induced systemic resistance (ISR), triggering the production of important defence enzymes like peroxidases, polyphenol oxidases and chitinases, helping the plant to resist microbial threats (Chen *et al.*, 2025). These enzymes suppress the nematode's survivability and lower its infectivity. Besides, by colonising the roots of host plants, *B. velezensis* contributes towards the development of such a microenvironment in soil that constrains nematode populations and promotes plant growth and improves such traits in plants, which lead to higher yield (Choi *et al.*, 2020).

This review aims to understand the mechanistic basis of the biocontrol capability of *B. velezensis* against the PPNs, particularly emphasising the diverse secondary metabolites it produces, the underlying enzymatic activities and volatile organic compounds (VOCs) secreted, contributing to its antagonism exhibited at the plant rhizosphere. This review also attempts to evaluate the practical application strategies using bioformulation technologies for enhancing the field efficacy and persistence of *B. velezensis* under various agroclimatic regimens.

Mechanisms of Nematicidal Action of *B. velezensis*

The biocontrol agents (in this case, *B. velezensis*), tackle the PPNs through a complex array of approaches. The mode of action and mechanism of *B. velezensis* involve the production of nematicidal volatiles and metabolites, along with efficient root colonization, which collectively prevent the establishment and proliferation of nematodes in host roots (Table 1; Figure 1). Besides, it improves the plant's self-defence against the invaders (PPNs) by induction of ISR, reducing the survival of nematodes.

Production of Anti-Nematicidal Secondary Metabolites

An important feature of *B. velezensis*'s effectiveness lies in its capability to produce various metabolites that act as weapons against nematodes. Amongst these, exist the well-known antibiotic compounds like fengycin, iturin and surfactin. They act by affecting the integrity of the cuticle of nematodes (the protective outer layer), the breaching of which leads to the death of the nematodes (Stoll *et al.*, 2021). Other than these metabolites, other secondary compounds like difficidin, macrolactins and bacillaene play important roles in suppressing nematodes through different mechanisms, *viz.*, protein synthesis inhibition, thereby stopping the growth and development of juveniles from eggs (Wu *et al.*, 2023). The previously mentioned compound, surfactin, can integrate into the cell membrane of nematodes, causing the critical ions (necessary for cellular functioning) to leak out, causing homeostasis disruption and leading to nematode paralysis. The metabolites iturin and fengycin produced by *B. velezensis* induce oxidative stress and affect the sterol-dependent membrane functions. Altogether, these compounds work in tandem and result in a net nematicidal effect on the target pathogens, without compromising ecological safety (Hu *et al.*, 2022).

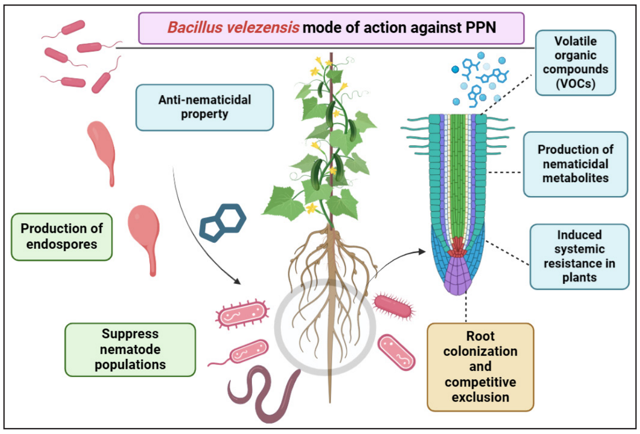

Figure 1: Multifaceted mode of action of *Bacillus velezensis* against plant-parasitic nematodes (PPNs)

In a study performed by Mian *et al.* (2024), it was observed lipopeptides like iturin and surfactin produced by *B. velezensis* strain Ag109 prevented egg hatching and causing juvenile mortality simultaneously in *Meloidogyne incognita*. Besides these lipopeptides, the biocontrol agent (BCA) synthesised polyketides like difficidin, bacillaene and macrolactins, known to interfere with the protein synthesis machinery in cells, thereby producing nematicidal effects. The effectiveness of this BCA extends beyond the lab. When applied in soybean crops, it was observed that a reduction of 69% and 45% populations of *M. javanica* and *Pratylenchus brachyurus* took place.

Computational analyses of metabolites reveal that 5-hydroxy-2-methylfurfural (HMF) and clindamycin produced by *B. velezensis* YEBBR6 can bind to several important proteins in the nematode *Radopholus similis*. These target proteins include sathepsin S-like cysteine proteinase, β-1,4-endoglucanase, reticulocalbin, venom allergen-like protein and serine carboxypeptidase. By interfering with these essential proteins, the metabolites are thought to disrupt necessary physiological functions, revealing their potent nematicidal potential (Saravanan *et al.*, 2022).

Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) have the ability to diffuse through the soil pores without contacting the bacteria and nematodes directly. Besides being toxic, VOCs tend to repel the nematodes away from colonized zones of the roots. *B. velezensis* produces such VOCs that disrupt nematode chemotaxis towards the roots of the host plant and suppress the populations of the second-stage (J2) juveniles penetrating the host tissues. Their ability to disrupt host-finding mechanisms in nematodes is a unique population-level mechanism limiting the establishment and reproduction of nematodes.

VOCs like benzaldehyde, 2-decanol and 2-undecanone produced by *B. velezensis* TA-1 showed toxicity towards the J2 of *M. incognita,* with the compounds benzaldehyde and 2-undecanone exhibiting fumigant activity. *In vitro* studies demonstrated that these VOCs resulted in 84% mortality of the juveniles within 48 h and increased to 93% by 72 h. The impact of these VOCs extends to the molecular level, where they were found to interfere with the key nematode genes. Specifically, they suppressed the transcription of *mpk-1*, *flp-18* and *ord-1* by 61%, 44.8% and 54.5%, respectively. As these genes play important roles in signalling pathways, their downregulation is indicative of the fact that such compounds can disrupt the nematode's ability to communicate signals at the cellular level (Ji *et al.*, 2025).

Similarly, researchers observed six major VOCs that were produced during the fermentation of *B. velezensis* GJ-7. These included 3-methyl-1-butanol, 3-methyl-2-pentanone, 5-methyl-2-hexanone, 2-heptanone, 2,5-dimethylpyrazine and 6-methyl-2-heptanone. These volatiles had direct toxic effects on the J2 of *M. hapla* and greatly reduced the hatching of their eggs, as was evidenced by bioassay experimentation in 24-well plates. Additionally, it was observed that volatiles, *viz.*, 3-methyl-1-butanol and 2-heptanone, exhibited high fumigant activity and killed the nematode's eggs and juveniles through vapour-phase exposure (Wu *et al.*, 2023).

Another study conducted by Tian *et al.* (2022) showed that upon exposing the eggs and juveniles of *M. incognita* to the fermentation volatiles produced by *B. velezensis* strain Bv-25, complete mortality was observed within just 12 h of exposure. Studies pertaining to its underlying mechanism revealed downregulation of essential nematode genes like ord-1, mpk-1 and flp-18, 48 h post exposure to the VOCs.

Hydrolytic Enzymes and Cuticular Degradation

The hydrolytic enzymes produced by *B. velezensis* play an important role in suppressing the PPNs. In an interesting study made by (Asaturova *et al.*, 2022), it was observed that *B. velezensis* strain BZR 86 and BZR 277 play a dual role in cucumber cultivation, by promoting yield increments ranging from 4.5-45% and at the same time control *M. incognita* through their bionematicidal activity. The chitinolytic activity of BZR 86 and the lipo-proteolytic enzymatic activity of BZR 277 are considered to be the key contributors towards nematode suppression. Proteases make the nematodes more prone to environmental stressors by degrading the nematode's cuticle and increasing the cuticular permeability. Chitinases target chitin-rich components of nematode eggshells, thereby reducing hatching success and interrupting the life cycle, while lipases disrupt the epicuticular lipid matrix and facilitate the penetration of antimicrobial compounds.

Upon treating the seedlings of *Pinus tabuliformis* with *B. velezensis* Pt-RP9, a reduction in the membrane lipid peroxidation was observed with a simultaneous increase in defence-related enzymes such as peroxidase (POD), catalase (CAT) and polyphenol oxidase (PPO). Such biochemical changes are an indicative of host resistance activation against *Bursaphelenchus xylophilus* (pine wood nematode). Also, the bacterial strain suppressed the nematode by approximately 70% (Sun *et al.*, 2024).

Anti-Nematode Compounds (ANCs)

Two compounds with nematicidal properties were identified from the fermentation broth produced on the shrimp shell powder, namely thymine and hexahydropyrrolo[1,2-a]pyrazine-1,4-dione. The former compound exhibited near complete mortality of *M. incognita* J2 (suppressing egg hatching by 70%), whereas the latter compound reduced the egg hatching by 58% showing moderate nematicidal action. Molecular docking analysed revealed the interaction of both of these compounds with the target acetylcholinesterase, leading to interference with neuromuscular function, leading to nematode suppression (Trinh *et al.*, 2022).

Induced Systemic Resistance (ISR)

Augmenting the soil microbiome with beneficial plant growth-promoting rhizobacteria (PGPR) strengthens the plant's defence system by activating various signalling pathways that confer enhanced resistance to biotic stresses (Sankar *et al.*, 2021). Induced systemic resistance (ISR) is a key mechanism through which *Bacillus velezensis* contributes to sustained nematode suppression. *B. velezensis*, upon colonising the plant roots, causes accumulation of callose, lignin, phytoalexins and pathogenesis-related proteins, due to the activation of jasmonic acid (JA) and ethylene (ET). Such defence responses result in the reduction of nematode penetration due to reinforced cell walls of roots and inhibit the establishment of their feeding sites. Also, the plants primed with microbes can show resistance even without the continuous association of the microbes and therefore the plants get 'vaccinated' against the pathogen in question.

Hu *et al.* (2024) reported that *B. velezensis* A-27 effectively triggers induced systemic resistance (ISR) in red kidney bean, while simultaneously enhancing jasmonic acid production through the regulation of key enzymes in the α-linolenic acid metabolic route. The synchronised activation of JA-linked defence mechanisms plays a crucial role in strengthening the plant's defence system against the soybean cyst nematode. Besides, *B. velezensis* also enhances systemic tolerance by upregulating the activation of anti-oxidant enzymes like peroxidase, polyphenol oxidase and superoxide dismutase, which help the plant in managing oxidative stress by neutralising the reactive oxygen species accumulated during nematode infection, which minimises cellular damage and supports overall plant health.

When plants treated with *B. velezensis* VB7 were challenged with *Meloidogyne incognita*, they mounted a robust defence response characteristic of microbe-associated molecular pattern (MAMP)-triggered immunity. This was evident from the marked upregulation of key defence-related genes, including transcription factors like WRKY and MYB, along with metabolic genes such as LOX, PAL and PR, when compared to both infected and healthy control plants. Taken together, these findings point to a dual mode of action for VB7; it not only suppresses nematodes directly but also primes the plant's own systemic defences to respond more effectively to attack (Kamalanathan *et al.*, 2023). A similar strategy has been observed with *B. velezensis* RKN1111, which forms a persistent association with cucumber roots. This colonisation primes the plant to tolerate *M. incognita* infestation by activating systemic defence pathways, reinforcing the idea that these bacteria serve as both protectors and immune system boosters for their plant hosts (Ma *et al.*, 2025).

In tomato plants, application of *B. velezensis TA-1* led to improved lignification and higher hydrogen peroxide accumulation. There was also an upregulation of PAL, PO and other defence-related enzymes and genes involved in salicylic acid-mediated (PR1a and PR-P6) and jasmonic acid-dependent (PI II and MC) signalling pathways, thereby providing the plants with resistance against *M. incognita* (Ji *et al.*, 2024).

Regulation of the Susceptible Gene

In vitro studies revealed that *B. velezensis* Bv-DS1 effectively controlled the fungal and nematode pathogens, killing about 71% of the *M. incognita* juveniles. In the greenhouse trials, it was observed that treatment with Bv-DS1 reduced the root galls by 48% and egg mass by 65%. The nematodes were unable to suppress the plant-aquaporin genes (TIP1.1 and TIP1.3), in the presence of the BCA, thereby allowing the plants to restore the nutrient flow and water level in the damaged root cells, thereby starving the nematodes and suppressing their growth (Hu *et al.*, 2022).

Rhizosphere Modulation

B. velezensis is an effective BCA because of its ability to reshape the host's rhizosphere. The bacterium thrives on the host's root exudates and rapidly colonizes the roots, outcompeting the pests. This was demonstrated using the *B. velezensis* strain A-27, which was able to achieve 67% reduction in the nematode damage and lowered the nematode infection significantly. Beyond its direct effects on the plant and the nematode, this biocontrol agent also left its mark on the surrounding soil. Its introduction reshaped the microbial community, actively promoting the proliferation of other beneficial microorganisms. This restructuring of the root microbiome created a more hostile environment for nematodes while simultaneously fostering conditions that supported better plant health and resilience (Yao *et al.*, 2025).

Plant Growth Promotion and Stress Mitigation

In addition to its protective role, *B. velezensis* actively contributes to soil fertility. It facilitates nitrogen fixation, phosphorus solubilization and siderophore production, processes that make essential nutrients more readily available to plants (Rostami *et al.*, 2024). This improved nutrient acquisition supports stronger, more vigorous root development, which naturally enhances the plant's ability to tolerate nematode pressure. The benefits extend even further. *B. velezensis* has also been shown to bolster plant resilience against abiotic stresses like drought and salinity. It helps regulate stress-responsive genes, improves water retention and maintains osmotic balance within plant tissues. By strengthening the plant's overall physiological state, these mechanisms indirectly reduce its vulnerability to nematode-induced damage, creating a more robust and resilient host (Wu *et al.*, 2023).

Nutrients like phosphorus and potassium are often present in the soil in insoluble form. *B. velezensis* tends to solubilise these nutrients and thereby enhances soil fertility. These nutrients then become bioavailable and can be easily absorbed by plants (Moreira *et al.*, 2025). *B. velezensis* offers yet another layer of benefit through its capacity to fix atmospheric nitrogen, a particularly valuable trait in nitrogen-deficient soils where plants would otherwise struggle. It also produces siderophores, specialised molecules that chelate iron from the surrounding environment and make it more accessible to the plant, further supporting healthy growth and development. Perhaps most notably, *B. velezensis* can synthesize a range of phytohormones that directly influence plant architecture and vitality. These include auxins like indole-3-acetic acid (IAA), which stimulate root elongation and promote the formation of lateral roots, leading to a more extensive root system. It also produces gibberellins, which regulate key developmental processes such as stem elongation and seed germination, along with cytokinins that encourage cell division and help delay leaf senescence. Together, these hormonal effects translate into increased biomass and improved overall yield (Pacifico *et al.*, 2021).

B. velezensis further strengthens the plant defence by boosting the production of phenolic and flavonoid compounds, fortifying the cell walls and acting as a barrier against the nematode entry. Its ability to orchestrate a comprehensive defence response by regulation of the stress hormones, neutralisation of the toxic reactive oxygen species, adds to its uniqueness and benefits. This helps the plants to manage both biological and environmental stressors and helps the plants to maintain their physiological balance under nematode attack.

Compatibility of *B. velezensis* with Other Biological Control Agents

Emerging research suggests that *B. velezensis* is even more effective when it has company. Used synergistically with other biocontrol agents, particularly fungi from the *Trichoderma* genus, it achieves greater suppression of root-knot nematodes than either agent could alone. A compelling example comes from a rhizosphere-engineering study in tomatoes, where researchers combined *B. velezensis* strain VB7 with *Trichoderma koningiopsis*. This dual application did more than just improve nematode control; it also boosted overall soil microbial diversity. The findings support a growing consensus that co-inoculation fosters a more robust and resilient defensive network in the root zone, leading to more stable, long-term biocontrol efficacy (Vinothini *et al.*, 2024). Greenhouse studies targeting *Meloidogyne javanica* have further confirmed this synergistic effect. The combination of *B. velezensis* and *T. harzianum* significantly reduced nematode reproduction and minimized plant damage compared to single-strain treatments. This appears to be a functional partnership: the bacterium's potent metabolite-based suppression complements the fungus's ability to aggressively colonize roots and dominate the rhizosphere, creating a formidable barrier against nematode attack (Rostami *et al.*, 2024). Altogether, these findings support the compatibility of *B. velezensis* with select fungal bioagents as a practical route to broaden modes of action and improve robustness of biological nematode management, particularly in systems where single-agent efficacy can be variable across soils and seasons.

Bioformulation of *Bacillus velezensis* for Nematode Management

For all its promise in the lab, the real-world field efficacy of *B. velezensis* hinges on one critical factor: formulation quality. A successful formulation must do two things well, it needs to keep bacterial spores viable during storage and it must ensure that once applied, those spores can quickly establish themselves and persist in the root zone where they're needed most (Sudhalakshmi, 2021). *B. velezensis*, endowed with functional traits such as the formation of endospores, production of nematicidal compounds, antagonistic activity, colonization ability and plant growth activity, making it effective through soil application for nematode management, thereby significantly reducing root galling and juvenile nematode populations (Figure 2). For instance, when the A-27 strain was applied in fields, a reduction in *M. incognita* infection and improved plant growth was observed, confirming the practical viability of these soil-based application strategies (Yao *et al.*, 2025). Likewise, *B. velezensis* strain YS-AT-DS1 showed in vitro juvenile mortality and effective biocontrol activity in pot-culture studies against *M. incognita* (Hu *et al.*, 2022).

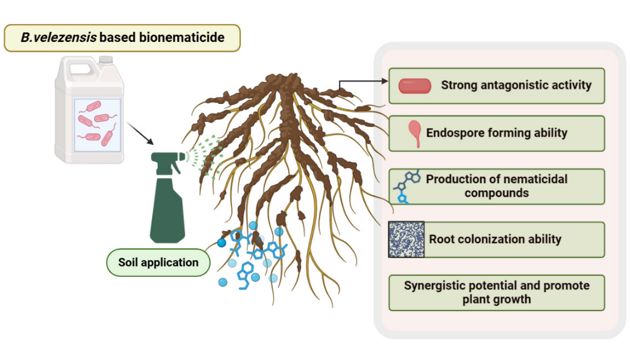

Figure 2: Key functional traits of *Bacillus velezensis* as a bionematicide in soil application

Advancements in the formulation technology have enhanced the efficiency and shelf-life of *B. velezensis* bionematicides. Encapsulation using polymers like alginate, chitosan and starch protects bacterial spores from abiotic and biotic stressors and allows their controlled release in soil. For example, microencapsulation of *B. velezensis* in alginate-gum polymer matrices has proven effective in achieving high encapsulation rates and controlled release profiles, maintaining a functional population of bacteria in the host plant's rhizosphere (Moradi Pour *et al.*, 2022). Such formulation strategies enhance bacterial survival, improve consistency of field performance and increase the practicality of *B. velezensis* for large-scale agricultural use (Asaturova *et al.*, 2022).

Future Perspectives

The imperative to perform long-term field trials for determining the lasting impact and ecological safety of *B. velezensis* cannot be ignored. Such studies will help in understanding how continuous applications of this BCA affect soil life, nutrient cycles and yields. Although most studies emphasise single-strain treatments, in the future, carefully selected consortia need to be tested and tried. Combining *B. velezensis* with complementary partners like *Trichoderma* spp., other beneficial PGPR and mycorrhizal fungi may offer a promising path to improved and stable control of pests and pathogen communities.

Future studies should integrate omics related aspects like genomics, transcriptomics, metabolomics and proteomics for identifying *B. velezensis* strains having superior nematicidal potential. Synthetic biological approaches like CRISPR-based genome editing can improve metabolite production or enable the genesis of novel biosynthetic pathways. Simultaneously, continued advances in formulation sciences are expected to play an important role in improving the performance of the BCA (or the products thereof) in the field conditions. Nano-based delivery systems, such as lipid and polymer-based nanoparticles can increase the stability and bioavailability of *B. velezensis*-derived metabolites and improve their persistence and movement within the soil pores. Finally, optimising carrier materials, shelf life and compatibility with standard farming practices will be essential for widespread commercial adoption.

From a translational perspective, developing cost-effective *B. velezensis* bioformulations that replace or complement chemical nematicides is vital for adoption, especially in resource-limited, price-sensitive systems. Future research should focus on molecular and omics approaches to understand strain-specific nematode suppression, host immune priming and rhizosphere colonization, guiding the selection of strains and consortia. Incorporating *B. velezensis* into precision agriculture and IPM will improve their reliability and marketability amid changing climatic and regulatory environments.

Table 1: Mode of actions of different strains of *B. velezensis* against major plant pathogenic nematodes (PPNs)

Plant-Parasitic Nematode (PPN)	Host Plant	*Bacillus velezensis* Strain	Mode of Action	Key Findings	References
Meloidogyne incognita	Tomato (*Solanum lycopersicum*)	Bv-DS1	Upregulation of Tonoplast intrinsic proteins (TIPs)	Reduction in gall numbers by 48.42% and egg masses by 64.81%	Hu *et al.*, 2022
Meloidogyne incognita	Celery (*Apium graveolens*)	A-27	Modulation of the rhizosphere microbial community.	Larvicidal and ovicidal efficacy *in vitro*	Yao *et al.*, 2025
Meloidogyne incognita	Tomato (*Solanum lycopersicum*)	VB7	MAMP-triggered immunity *viz.*, Upregulation of defence genes *WRKY, LOX, PAL, MYB* and *PR*	Nematode eggs and juvenile mortality of *M. incognita* by 87.95% and 96.66%	Kamalanathan *et al.*, 2023
Meloidogyne incognita	Cucumber (*Cucumis sativus*)	TA-1	Volatile organic compounds (VOCs)	Mortality rate of 84.1% at 48 h and 92.8% at 72 h to *M. incognita* J2.	Ji *et al.*, 2025
Meloidogyne incognita	Tomato (*Solanum lycopersicum* L.)	TA-1	Accumulation of lignin and hydrogen peroxide and other defense enzymes	Reduced the number of galls by 44.0%	Ji *et al.*, 2024
Meloidogyne incognita	Cucumber (*Cucumis sativus*)	RKN1111	Increased hydrogen peroxide (H_2O_2) and superoxide anion (O^{2-}) contents and callose deposition	Reduction of 78.19% root galls	Ma *et al.*, 2025
Meloidogyne incognita	Cucumber (*Cucumis sativus*)	BZR 86 and BZR 277	Enzymatic degradation (chitinases, lipases and proteases)	Two times reduction in root galls.	Asaturova *et al.*, 2022
Meloidogyne incognita	Cucumber (*Cucumis sativus*)	Bv-25	Volatile organic compounds (VOCs)	Reduced cucumber root knots by 73.8%.	Tian *et al.*, 2022

Plant-Parasitic Nematode (PPN)	Host Plant	*Bacillus velezensis* Strain	Mode of Action	Key Findings	References
Meloidogyne incognita	Black pepper (*Piper nigrum*)	RB.EK7	Inhibit the enzyme acetylcholinesterase	64.2% mortality of J2 nematodes and an anti-egg hatching effect of 57.9%	Trinh *et al*., 2022
Meloidogyne hapla	Chinese ginseng (*Panax notoginseng*)	GJ-7	Volatile organic compounds (VOCs)	Mortality rates of J2s were 85% at 24 h and 97.1% at 48 h after VOCs treatment	Wu *et al*., 2023
Meloidogyne hapla	Strawberry (*Fragaria ananassa*)	FC37	ISR response	Reduced galling index	Camacho *et al*., 2023
Heterodera glycines	Red kidney bean (*Phaseolus vulgaris* L.)	A-27	Induce JA biosynthesis	Increase in JA content in the roots.	Hu *et al*., 2024
Pratylenchus sp.	Fern (*Rumohra adiantiformis*)	-	Structural damage to the nematode cuticle	Reduced the motility and increased the mortality of J2	Wahyuningsih *et al*., 2025
Meloidogyne javanica and *Pratylenchus brachyurus*	Soybean [*Glycine max* (L.) Merr.]	Ag109	Lipopeptides (LPs) production (surfactin and fengycin)	Controlled 69% and 45% of the populations of *Meloidogyne javanica* and *Pratylenchus brachyurus*, respectively	Mian *et al*., 2024
Radopholus similis	Banana (*Musa* spp.)	(YEBBR6)	Antagonistic metabolite production	Inhibitor of the target protein sites	Saravanan *et al*., 2022
Rotylenchulus reniformis	Cotton (*Gossypium hirsutum*)	Bve2	ISR response	Reduced total number of eggs at 45 days after planting	Xiang *et* al., 2018
Ditylenchus destructor	Potato (*Solanum* spp.)	b5-4	ISR response	72.36-82.59% corrected mortality	Niu *et al*., 2021
Bursaphelenchus xylophilus	Pine (*Pinus tabuliformis*)	Pt-RP9	Reduced lipid peroxidation levels along with increased peroxidase, catalase and polyphenol oxidase	Control efficiencies of 68.89% under *in vivo* conditions	Sun *et al*., 2024

Conclusion

Bacillus velezensis has emerged as a versatile biological agent for the management of plant-parasitic nematodes (PPNs) because of its multifaceted modes of action, including the production of potent lipopeptides, polyketides and volatile organic compounds (VOCs), as well as the activation of host-induced systemic resistance and modulation of key defence pathways. *B. velezensis* strains consistently suppress egg hatching, reduce juvenile survival, alter nematode gene expression and enhance plant physiological resilience, as revealed in various studies across the globe. Such effects result in a significant reduction in nematode populations and improvements in plant growth and yield. Future studies need to emphasise broader field validation, optimised formulations and strategically designed microbial consortia are required to fully realise the practical application of this BCA in agriculture. Integration of *B. velezensis*-based strategies into holistic integrated pest management frameworks offers an environmentally responsible alternative to chemical nematicides and supports long-term soil health and crop productivity.

Ethical Statement

The authors declare that no generative artificial intelligence tools were used in drafting or preparing this manuscript. The manuscript was written, interpreted and revised solely by the authors, who take full responsibility for its content.

References

Asaturova, A.M., Bugaeva, L.N., Homyak, A.I., Slobodyanyuk, G.A., Kashutina, E.V., Yasyuk, L.V., Sidorov, N.M., Nadykta, V.D., Garkovenko, A.V., 2022. *Bacillus velezensis* strains for protecting cucumber plants from root-knot nematode *Meloidogyne incognita* in a greenhouse. *Plants* 11(3), 275. DOI: https://doi.org/10.3390/plants11030275.

Camacho, M., de los Santos, B., Vela, M.D., Talavera, M., 2023. Use of bacteria isolated from berry rhizospheres as biocontrol agents for charcoal rot and root-knot nematode strawberry diseases. *Horticulturae* 9(3), 346. DOI: https://doi.org/10.3390/horticulturae9030346.

Chen, Z., Zhang, H., Lv, W., Zhang, S., Du, L., Li, S., Zhang, H., Zheng, X., Zhang, J., Zhang, T., Bai, N., 2025. *Bacillus velezensis* SS-20 as a potential and efficient multifunctional agent in biocontrol, saline-alkaline tolerance and plant-growth promotion. *Applied Soil Ecology* 205, 105772. DOI: https://doi.org/10.1016/j.apsoil.2024.105772.

Choi, T.G., Maung, C.E.H., Lee, D.R., Henry, A.B., Lee, Y.S., Kim, K.Y., 2020. Role of bacterial antagonists of fungal pathogens, *Bacillus thuringiensis* KYC and *Bacillus velezensis* CE 100 in control of root-knot nematode, *Meloidogyne incognita* and subsequent growth promotion of tomato. *Biocontrol Science and Technology* 30(7), 685-700. DOI: https://doi.org/10.1080/09583157.2020.1765980.

Desaeger, J., Wram, C., Zasada, I., 2020. New reduced-risk agricultural nematicides-rationale and review. *Journal of Nematology* 52(1), e2020-91. DOI: https://doi.org/10.21307/jofnem-2020-091.

Figueiredo, J.E.F., Diniz, G.D.F.D., Marins, M.S., Silva, F.C., Ribeiro, V.P., Lanza, F.E., Oliveira-Paiva, C.A.D., Cruz-Magalhães, V., 2025. *Bacillus velezensis* CNPMS-22 as biocontrol agent of pathogenic fungi and plant growth promoter. *Frontiers in Microbiology* 16, 1522136. DOI: https://doi.org/10.3389/fmicb.2025.1522136.

Hu, Y., Ma, Y., Wang, L., Luo, Q., Zhao, Z., Wang, J., Xu, Y., 2024. Research on the mechanism of *Bacillus velezensis* A-27 in enhancing the resistance of red kidney beans to soybean cyst nematode based on TMT proteomics analysis. *Frontiers in Plant Science* 15, 1458330. DOI: https://doi.org/10.3389/fpls.2024.1458330.

Hu, Y., You, J., Wang, Y., Long, Y., Wang, S., Pan, F., Yu, Z., 2022. Biocontrol efficacy of *Bacillus velezensis* strain YS-AT-DS1 against the root-knot nematode *Meloidogyne incognita* in tomato plants. *Frontiers in Microbiology* 13, 1035748. DOI: https://doi.org/10.3389/fmicb.2022.1035748.

Ji, X., Fan, M., Wang, D., Zhang, S., Zhang, S., Liu, Y., Qiao, K., 2025. Volatile organic compounds (VOCs) of *Bacillus velezensis* TA-1 exhibit toxic effects against *Meloidogyne incognita*. *Journal of Pest Science* 98, 509-519. DOI: https://doi.org/10.1007/s10340-024-01815-9.

Ji, X., Liu, B., Fan, M., Zhang, S., Liu, Y., Zhang, S., Wang, Z., Qiao, K., 2024. Biocontrol of *Meloidogyne incognita* by *Bacillus velezensis* TA-1 through induction of host resistance in tomato. *Journal of Pest Science* 97, 2227-2236. DOI: https://doi.org/10.1007/s10340-024-01742-9.

Jones, J.T., Haegeman, A., Danchin, E.G., Gaur, H.S., Helder, J., Jones, M.G., Kikuchi, T., Manzanilla-López, R., Palomares-Rius, J.E., Wesemael, W.M., 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.

Kamalanathan, V., Nakkeeran, S., Saranya, N., 2023. Antagonistic bacteria *Bacillus velezensis* VB7 possess nematicidal action and induce an immune response to suppress the infection of root-knot nematode (RKN) in tomato. *Genes* 14(7), 1335. DOI: https://doi.org/10.3390/genes14071335.

Ma, J., Li, K., He, L., Wang, N., Xu, Y., Tong, X., Li, R., Zhang, A., Zhao, G., Cao, D., 2025. *Bacillus velezensis* RKN1111 enhances resistance against *Meloidogyne incognita* in *Cucumis sativus*. *Pest Management Science* 81(6), 3403-3409. DOI: https://doi.org/10.1002/ps.8714.

Mian, S., Machado, A.C.Z., Hoshino, R.T., Mosela, M., Higashi, A.Y., Shimizu, G.D., Teixeira, G.M., Nogueira, A.F., Giacomin, R.M., Ribeiro, L.A.B., Koltun, A., 2024. Complete genome sequence of *Bacillus velezensis* strain Ag109, a biocontrol agent against plant-parasitic nematodes and *Sclerotinia sclerotiorum*. *BMC Microbiology* 24(1), 194. DOI: https://doi.org/10.1186/s12866-024-03282-9.

Moradi Pour, M., Saberi Riseh, R., Ranjbar-Karimi, R., Hassanisaadi, M., Rahdar, A., Baino, F., 2022. Microencapsulation of *Bacillus velezensis* using alginate-gum polymers enriched with TiO_2 and SiO_2 nanoparticles. *Micromachines* 13(9), 1423. DOI: https://doi.org/10.3390/mi13091423.

Moreira, A.C.S., Lopes, E.A., Visôtto, L.E., Soares, M.S., Londe, M.L.A., Ribeiro, L.B., Terra, W.C., Moreira, S.I., Pedroso, M.P., Pereira, L.F., dos Reis, C.N., 2025. *Bacillus amyloliquefaciens* strain BaNCT02: An antagonist with multiple mechanisms of action against *Meloidogyne incognita*. *Plant Pathology* 74(2), 320-329. DOI: https://doi.org/10.1111/ppa.14021.

Nicol, J.M., Turner, S.J., Coyne, D.L., Nijs, L.D., Hockland, S., Maafi, Z.T., 2011. Current nematode threats to world agriculture. In: *Genomics and Molecular Genetics of Plant-Nematode Interactions*. (Eds.) Jones, J., Gheysen, G. and Fenoll, C. Springer, Dordrecht, Netherlands. pp. 21-43. DOI: https://doi.org/10.1007/978-94-007-0434-3_2.

Niu, Z., Dong, W., Yuanzheng, Z., Peng, X., Tingyan, Q., Xin, Z., Tengda, G., Zhichao, G., Hongyou, Z., 2021. Biocontrol Bacteria against *Ditylenchus destructor*: Screening and Identification. *Chinese Agricultural Science Bulletin* 37(18), 138-146. DOI: https://doi.org/10.11924/j.issn.1000-6850.casb2020-0605.

Pacifico, M.G., Eckstein, B., Bettiol, W., 2021. Screening of Bacillus for the development of bioprotectants for the control of *Fusarium oxysporum* f. sp. *vasinfectum* and *Meloidogye incognita*. *Biological Control* 164, 104764. DOI: https://doi.org/10.1016/j.biocontrol.2021.104764.

Rabbee, M.F., Hwang, B.S., Baek, K.H., 2023. *Bacillus velezensis*: A beneficial biocontrol agent or facultative phytopathogen for sustainable agriculture. *Agronomy* 13(3), 840. DOI: https://doi.org/10.3390/agronomy13030840.

Rostami, M., Shahbazi, S., Soleimani, R., Ghorbani, A., 2024. Optimizing sustainable control of *Meloidogyne javanica* in tomato plants through gamma radiation-induced mutants of *Trichoderma harzianum* and *Bacillus velezensis*. *Scientific Reports* 14(1), 17774. DOI: https://doi.org/10.1038/s41598-024-68365-z.

Sankar, P.M., Shreedevasena, S., Kaviyarathinam, T., Syamala, M., 2021. A multi-trait mechanisms of PGPR in plant disease management. *Biotica Research Today* 3(5), 382-385.

Saravanan, R., Saranya, N., Ragapriya, V., Rajaswaminathan, V., Kavino, M., Krishnamoorthy, A.S., Nakkeeran, S., 2022. Nematicidal property of clindamycin and 5-hydroxy-2-methyl furfural (HMF) from the banana endophyte *Bacillus velezensis* (YEBBR6) against banana burrowing nematode *Radopholus similis*. *Indian Journal of Microbiology* 62(3), 364-373. DOI: https://doi.org/10.1007/s12088-022-01011-2.

Stoll, A., Salvatierra-Martínez, R., González, M., Araya, M., 2021. The role of surfactin production by *Bacillus velezensis* on colonization, biofilm formation on tomato root and leaf surfaces and subsequent protection (ISR) against *Botrytis cinerea*. *Microorganisms* 9(11), 2251. DOI: https://doi.org/10.3390/microorganisms9112251.

Sudhalakshmi, C., 2021. Rhizosphere - A perfect soil engineer. *Biotica Research Today* 3(5), 393-395.

Sun, M., Liang, C., Fu, X., Liu, G., Zhong, Y., Wang, T., Tang, G., Li, P., 2024. Nematocidal activity and biocontrol efficacy of endophytic *Bacillus velezensis* Pt-RP9 from *Pinus tabuliformis* against pine wilt disease caused by *Bursaphelenchus xylophilus*. *Biological Control* 196, 105579. DOI: https://doi.org/10.1016/j.biocontrol.2024.105579.

Tian, X.L., Zhao, X.M., Zhao, S.Y., Zhao, J.L., Mao, Z.C., 2022. The biocontrol functions of *Bacillus velezensis* strain Bv-25 against *Meloidogyne incognita*. *Frontiers in Microbiology* 13, 843041. DOI: https://doi.org/10.3389/fmicb.2022.843041.

Trinh, T.H.T., Wang, S.L., Nguyen, V.B., Phan, T.Q., Doan, M.D., Tran, T.P.H., Nguyen, T.H., Le, T.A.H., Ton, T.Q., Nguyen, A.D., 2022. Novel nematocidal compounds from shrimp shell wastes valorized by *Bacillus velezensis* RB.EK7 against black pepper nematodes. *Agronomy* 12(10), 2300. DOI: https://doi.org/10.3390/agronomy12102300.

Vasantha-Srinivasan, P., Park, K.B., Kim, K.Y., Jung, W.J., Han, Y.S., 2025. The role of Bacillus species in the management of plant-parasitic nematodes. *Frontiers in Microbiology* 15, 1510036. DOI: 10.3389/fmicb.2024.1510036.

Vinothini, K., Nakkeeran, S., Saranya, N., Jothi, P., Richard, J.I., Perveen, K., Bukhari, N.A., Glick, B.R., Sayyed, R.Z., Mastinu, A., 2024. Rhizosphere engineering of biocontrol agents enriches soil microbial diversity and effectively controls root-knot nematodes. *Microbial Ecology* 87(1), 120. DOI: https://doi.org/10.1007/s00248-024-02435-7.

Wahyuningsih, F., 2025. PENGENDALIAN *Pratylenchus* sp. PADA TANAMAN PAKIS (*Rumohra adiantiformis*) MENGGUNAKAN *Bacillus velezensis* DAN *Bacillus tropicus*. *Doctoral Dissertation*, Universitas Gadjah Mada, Yogyakarta.

Wu, W., Zeng, Y., Yan, X., Wang, Z., Guo, L., Zhu, Y., Wang, Y., He, X., 2023. Volatile organic compounds of *Bacillus velezensis* GJ-7 against *Meloidogyne hapla* through multiple prevention and control modes. *Molecules* 28(7), 3182. DOI: https://doi.org/10.3390/molecules28073182.

Xiang, N., Lawrence, K.S., Kloepper, J.W., Donald, P.A., 2018. Biological control of *Rotylenchulus reniformis* on soybean by plant growth-promoting rhizobacteria. *Nematropica* 48(1), 116-125.

Yao, Y., Wang, L., Zhai, H., Dong, H., Wang, J., Zhao, Z., Xu, Y., 2025. *Bacillus velezensis* A-27 as a potential biocontrol agent against *Meloidogyne incognita* and effects on rhizosphere communities of celery in field. *Scientific Reports* 15(1), 1057. DOI: https://doi.org/10.1038/s41598-024-83687-8.