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Beneath the roots: Role of plant growth-promoting rhizobacteria (PGPR) in controlling nematode population in chilli (*Capsicum annuum L.*)

M.Tejashree[1], S. Triveni[1], J . Sai Prasad[2], P. Samata[3], D. Sridevi[4]

1 Department of Agricultural Microbiology and Bioenergy, College of Agriculture, PJTAU, Rajendranagar, Hyderabad – 500036, Telangana, India

2 Professor and Head, Sheep Breeding Research Station, Sandynallah, The Nilgiris, TANUVAS, 643237 Tamil Nadu, India

3 Department of Agronomy, Regional Sugarcane and Rice Research Station, Rudrur, PJTAU, Nizamabad District - 503188, Telangana India

4 Department of Agricultural Microbiology and Bioenergy, College of Agriculture, PJTAU, Rajendranagar, Hyderabad – 500036, Telangana, India

Corresponding authors email: tjsri5@gmail.com

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Introduction

Chilli (*Capsicum annuum* L.) is among India's most economically important spice and vegetable crops. Its cultivation, however, is seriously constrained by the root-knot nematode, *Meloidogyne* incognita and *M. javanica*, which invade roots and induce characteristic galls. These galls impair water and nutrient uptake and create wounds through which secondary pathogens such as *Fusarium* and *Ralstonia* enter, converting a nematode problem into a disease complex that can cause severe yield loss. Chemical nematicides such as methyl bromide, aldicarb and carbofuran have long been used against root-knot nematodes, but many are now restricted owing to toxicity, environmental persistence and the development of tolerance in nematode populations. This has increased interest in Plant Growth-Promoting Rhizobacteria (PGPR) as an eco-friendly, residue-free alternative for nematode management in chilli.

PGPR as nematode managers

PGPR are root-associated bacteria that promote plant growth while also suppressing soil-borne pests and pathogens, including plant-parasitic nematodes. As natural inhabitants of the rhizosphere, they integrate with the existing soil microbiome rather than introducing external toxins, making them compatible with organic and sustainable chilli production systems.

Mechanisms of nematode suppression

PGPR strains active against root-knot nematodes typically combine more than one of the mechanisms summarised in Table 1, including direct nematicidal metabolites, enzymatic degradation of the nematode cuticle and eggs, inhibition of egg hatching, competitive rhizosphere colonisation, induction of systemic resistance in the host, and siderophore-mediated competition with nematode-associated microbes. Direct suppression is largely chemical: many strains secrete nematicidal secondary metabolites, hydrogen cyanide, or other volatile organic compounds that are toxic to second-stage juveniles, alongside extracellular enzymes such as chitinases, proteases and collagenases that degrade the protein- and chitin-rich nematode cuticle and egg shell, causing mortality before the pest can establish in the root (Vasantha-Srinivasan *et al.,* 2025). Indirect suppression works through the plant itself: root colonisation by PGPR activates jasmonic acid- and ethylene-mediated defence pathways, priming the plant to mount a faster, stronger response once nematodes attack, a phenomenon known as induced systemic resistance (ISR). Dense rhizosphere colonisation also alters root exudate chemistry, making roots less attractive as infection sites, while siderophore production limits the iron available to nematode-associated microbes, indirectly weakening the nematode's supporting microflora.

Table 1: Mechanisms by which PGPR suppress root-knot nematode populations

Mechanism	**Mode of action against the nematode**
Nematicidal metabolites / VOCs	Toxic and volatile compounds kill or immobilise second-stage juveniles (J2) before root invasion
Cuticle- and egg-degrading enzymes	Chitinases, proteases and collagenases break down the nematode cuticle and egg shell
Egg-hatch inhibition	Bacterial metabolites interfere with hatching cues, reducing the next generation
Rhizosphere competition	Root colonisation alters exudate chemistry, making roots less attractive to nematodes
Induced Systemic Resistance (ISR)	Colonisation primes jasmonic acid / ethylene defence pathways in the host
Siderophore-mediated iron competition	Limits iron availability to nematode-associated microbes and competing pathogens

Reports from chilli and related crops

Several published studies have demonstrated activity of specific PGPR against root-knot nematodes in chilli and related solanaceous crops (Table 2). Wahla *et al.,* (2012) reported that *Pseudomonas aeruginosa* strains isolated directly from chilli rhizosphere suppressed M. incognita in both laboratory and pot studies. Viljoen *et al.,* (2019) screened 27 PGPR strains and found *Bacillus firmus,* B. aryabhattai and *Paenibacillus spp.* caused large reductions in gall numbers on tomato and carrot. Vasantha-Srinivasan *et al.,*. (2025) reviewed nematicidal enzymes and metabolites produced by *Bacillus subtilis* and related species. Wong-Villarreal *et al.,* (2021) recovered an endophytic *Serratia ureilytica* strain from chilli tissue with nematicidal activity, while Antil *et al.,* (2023) documented nematicidal biomolecules from endophytic Bacillus cereus isolates active against *Meloidogyne spp.*

Field application strategies

Practical delivery routes for chilli include seed bacterisation before sowing, dipping nursery seedling roots in a bacterial suspension prior to transplanting, and enriching soil with carrier-based PGPR formulations mixed into farmyard manure or vermicompost.

Early application, before nematode populations build up, allows the bacteria to establish in the root zone. Combining PGPR with organic amendments such as neem cake can further enhance suppression, since organic matter both nourishes the beneficial bacteria and has intrinsic nematode-suppressive activity.

Table 2: bacterial genera reported to suppress root-knot nematodes in chilli and related crops

Bacterium	Reported activity
Pseudomonas aeruginosa (chilli rhizosphere isolates)	Reduced *M. incognita* infection on chilli in vitro and in vivo (Wahla *et al.*, 2012)
Bacillus firmus, B. aryabhattai, Paenibacillus spp.	Large reductions in root-gall numbers on solanaceous vegetable crops (Viljoen *et al.*, 2019)
Bacillus subtilis and *related Bacillus spp.*	Nematicidal enzymes and metabolites (fengycin, surfactin) degrade cuticle and cause juvenile mortality (Vasantha-Srinivasan *et al.*, 2025)
Serratia ureilytica (chilli endophyte)	Nematicidal activity against a root-knot-like nematode in chilli tissue (Wong-Villarreal *et al.*, 2021)
Bacillus cereus and other endophytic isolates	Nematicidal biomolecules active against *Meloidogyne* spp. (Antil *et al.*, 2023)

Benefits and future outlook

Because root-knot nematodes frequently act together with fungal and bacterial wilt pathogens, suppressing nematode populations reduces both direct damage and secondary infection. PGPR multiply in soil rather than being depleted, so their benefit can persist and improve over successive seasons, unlike single-application chemical treatments. Realising this potential at scale will require location-specific strain selection, formulations with adequate shelf-life, multi-location field validation, and extension support to build farmer confidence in biological alternatives to chemical nematicides.

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