

## Evaluation of antagonistic *Pseudomonas* and *Bacillus* spp. against *Meloidogyne incognita* causing root-knot disease in okra

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**ABSTRACT:** Efficacy of antagonistic bacteria *Pseudomonas* and *Bacillus* against the root-knot nematode (*Meloidogyne incognita*) in okra as a sustainable biological control strategy was evaluated. All the bacterial treatments significantly reduced nematode populations and root galling while enhancing plant growth and yield compared to the control. Nematode-related parameters showed strong positive correlations among themselves: egg mass per plant ( $r = 0.998$ ), nematode population ( $r = 0.968$ ), and root-knot index ( $r = 0.907$ ), while plant growth parameters showed significant negative correlations with nematode infestation: plant height ( $r = -0.983$ ), fresh shoot weight ( $r = -0.988$ ), dry shoot weight ( $r = -0.990$ ), root length ( $r = -0.960$ ), fresh root weight ( $r = -0.996$ ), and dry root weight ( $r = -0.983$ ). Seed treatment with *P. fluorescens* at  $10\text{g kg}^{-1}$  was the most effective, giving the lowest root-knot index (3.33) and the greatest reduction in galls, egg masses, and larvae per 200 cc soil. Although carbofuran showed comparable efficacy, its environmental and health hazards limit its use; thus, seed treatment with *P. fluorescens* at  $10\text{g kg}^{-1}$  is recommended as an effective, eco-friendly alternative for managing *M. incognita* in okra.

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**KEY WORDS:** Seed treatment, yield loss, nematode population, root-knot index, galls

### INTRODUCTION

Okra [*Abelmoschus esculentus* (L.) Moench] is economically important annual herbaceous vegetable belonging to the family Malvaceae,

widely cultivated across tropical, subtropical, and warm temperate regions of the world. Plant parasitic nematodes are among the most significant biotic constraints limiting okra productivity

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worldwide. Leveraging the bio-synthesis of nanomaterials to combat with root knot nematodes also tested by Ghareeb *et al.* (2024). Notable nematodes that infect okra include species of *Meloidogyne*, *Hoplolaimus*, *Helicotylenchus*, *Tylenchorhynchus*, *Aphelenchus*, and *Rotylenchulus*. Root knot nematodes (RKN) being the most widespread and harmful (Bhosle *et al.*, 2004; Muthulaxmi *et al.*, 2010). RKN (*M. incognita*) are sedentary obligate endoparasites with a broad host range, infecting a wide diversity of vegetable crops and causing substantial yield losses (Kiewnick and Sikora, 2006; Sahebani and Hadavi, 2008; Elling, 2013). Crops such as tomatoes, okra, brinjal, chili, cluster beans, potatoes, and cucumbers are among the severely affected (Jain *et al.*, 2007). In okra, the nematode can complete its life cycle in just 28 days (Al-Sayed *et al.*, 2011). Symptoms of infestation include significant root galling and distortion, which can lead to yield reductions of as much as 90 per cent (Rao *et al.*, 2014). In India, the economic repercussions of this nematode are estimated to be around \$7.8 million (Jain *et al.*, 2007). Managing *M. incognita* in intensive agriculture poses challenges, as early signs of infestation are often overlooked, and leads to swift and severe losses in yield. Despite their prevalent use of the pesticides, there was reduction in yield losses (Oerke, 2006). This underscores the need for sustainable, eco-friendly alternatives to chemical nematicides (Copping and Menn, 2000; Lee and Kim, 2016; Patil *et al.*, 2020; Abd-Elgawad, 2021). Among these, antagonistic bacteria have emerged as highly promising biocontrol agents for plant-parasitic nematodes (Giannakou *et al.*, 2004; Ali *et al.*, 2023; Bhat *et al.*, 2023; Saharan *et al.*, 2023). These nematophagous bacteria utilize various strategies, including the secretion of toxins or enzymes, parasitizing hosts, triggering systemic resistance in plants, and promoting overall plant health (Gamliel and Katan, 1993; Tian *et al.*, 2007). Many species of *Bacillus* are effective in reducing nematode populations, particularly *M. incognita*. Species like *B. pumilus*, *B. megaterium*, *B. cereus*, and *B. thuringiensis* produce metabolites that significantly elevate mortality rates in the J2 stage of *Meloidogyne incognita* (Padgham and Sikora, 2007). However, systematic evaluation of specific

bacterial antagonists under field-relevant conditions in okra remains limited (Yadav *et al.*, 2022). The present study was undertaken to evaluate the *Pseudomonas* and *Bacillus* in suppressing *M. incognita* infestation and improving the growth and yield of okra.

## MATERIAL AND METHODS

During the 2019–2020 Rabi season, the study was carried out at the net house of the Department of Nematology at the College of Agriculture, O.U.A.T., Bhubaneswar, under pot culture conditions using earthen pots of 30cm diameter filled with 5kg of sterilized sandy loam soil, with two plants of okra genotype Utkal Gaurav (BO2), maintained per pot. The experiment was conducted using a Complete Randomized Design with eight treatments, each replicated three times (Table 2).

Freshly extracted second-stage juveniles (J2) of *M. incognita* were inoculated at the rate of 2000 J2 per pot by pipetting the inoculum suspension into holes made around the root zone at the time of transplanting. Seedlings were inoculated 10 days after sowing by pouring the nematode suspension near the root zone. The experiment was maintained for 60 days after inoculation, after which plants were uprooted for assessment of nematological and morphological parameters. All bioagents, *P. fluorescens*, *B. pumilus*, *B. subtilis*, *B. megaterium*, *P. putida*, and *B. amyloliquefaciens*, were used as talc-based formulations with a minimum viable count of  $1 \times 10^8$  CFU/g. Seeds were coated with the bioagents at  $10 \text{ g kg}^{-1}$  of seed using a small quantity of water as a sticking agent and shade-dried for 30 minutes before sowing. The morphological characteristics assessed for the okra varieties comprised plant height (cm), fresh shoot weight (g), dried shoot weight (g), root length (cm), fresh root weight (g), dry root weight (g), the count of galls per plant, the number of egg masses per plant, and the root knot index.

One kg sample of soil was taken from each pot and blended thoroughly, after which 200 cc of soil was extracted from each pot. The nematode populations in these soil samples were evaluated using Cobb's sieving method (Cobb, 1918) and the

modified Baermann funnel method (Schinder, 1961). The root galling index (1–5-point scale, Table 1) was conducted following the method outlined by Taylor and Sasser (1978).

Statistical analysis was done through OP stat. Correlation coefficients (Johnson *et al.*, 1955) were calculated to analyse the relationship between yield and other factors, as well as among yield components, physiological indicators, and quality attributes.

## RESULTS AND DISCUSSION

### Impact of bacterial antagonists seed treatment with 10 g kg<sup>-1</sup> on shoot growth of okra infected by root knot nematode:

The heights of the plants in different treatments descending order were - T1 *P. fluorescens* (53.6cm), T7 Carbofuran 3G @ 1kg a.i. ha<sup>-1</sup> (51.3cm), T3 *B. subtilis* (50.1cm), T2 *B. pumilus* (47.7cm), T5 *P. putida* (44.9cm), T6 *B. amyloliquefaciens* (40.7cm), and T4 *B. megaterium* (36.8cm), with respective increases of 65.3, 58.2, 54.5, 47.3, 38.6, 25.5, and 13.5% respectively, over control (T8). However, T1 and T7 were statistically similar. The highest fresh shoot weight was observed in T1 (88.8g, with 42.7% increase over the control), followed by T7 (86.4g, with 38.9% increase), T3 (85.6g, 37.6%), T2 (80.3g, 29.1%), T5 (77.1g, 23.9%), and T6 (73.2g, 17.6%).

Although T4 (68.4 g) had the least increase (10.0%), it was still statistically significant in compare with non-treated control (T1).

The dry shoot weight was notably high in T1 *P. fluorescens* (15.38g), followed by T3 *B. subtilis* (14.85g) but were statistically similar to T7 Carbofuran (14.71g). These were followed by T2 (13.31g), T5 (12.46g), and T6 (11.72g), showing increases of 45, 35.8, and 27.6 over the control (T8), respectively (Table 2, Fig. 1).

The study revealed that all bacterial antagonists used as seed treatments increased plant growth considerably. Using *P. fluorescens* resulted in notable increases in height of the plants, both fresh and dry shoot weight, length of the root, and fresh

and dry root weight. These findings align with those of Mahalik *et al.* (2020), who found that *P. fluorescens* showed better performance than other bacterial antagonists, such as *P. putida* and *Bacillus* spp., when applied individually. Similarly, Sharma *et al.* (2021) reported that seed and soil application of *P. fluorescens* along with mycorrhizal fungi reduced root-knot nematode infestation and enhanced growth in eggplant. Ali *et al.* (2023) recorded similar growth-promoting and nematode-suppressive benefits of microbial antagonists in okra under greenhouse conditions.

### Impact of bacterial antagonists on root growth of okra infected by root knot nematode:

The recorded root lengths of okra plants were: T1 (23.1cm), T2 (18.2cm), T3 (21.8cm), T4 (15.2cm), T5 (17.1cm), T6 (15.8cm), and T7 (22.7cm). All treatments showed significant improvement over the untreated check. Among them, T1 (*P. fluorescens* treatment of seeds at an application rate of 10 g kg<sup>-1</sup> of seed) had the highest percentage increase in mean root length at (76.6%), followed by T7 (73.6%) and T3 (66.1%). The smallest increase was seen in T4 (16.4%), compared to the untreated check T8. Results revealed with of fresh root weight data showed that T1 had the highest weight (18.74g), followed by T7 (17.91g), T3 (17.32g), and T2 (15.48g), with T8 having the lowest weight (10.42g). Treatment T1 was significantly different from all other treatments in fresh root weight except T7 (Utilizing Carbofuran 3G at 1 kg a.i.ha<sup>-1</sup>). The percentage increase in fresh root weight, in ascending order, was T4 (31.5%), T6

**Table 1. Nematode gall indexing through 5-point scale**

| No. of galls | Gall rating | Response                   |
|--------------|-------------|----------------------------|
| 0            | 0           | Non-responsive/control     |
| 1-2          | 1           | Extremely tolerant (ET)    |
| 3-10         | 2           | Tolerant (T)               |
| 11-30        | 3           | Partially Tolerant (PT)    |
| 31-100       | 4           | Susceptible (S)            |
| >100         | 5           | Extremely Susceptible (ES) |

**Table 2. Impact of bacterial antagonists on shoot growth of root knot nematode infected okra**

| Treatments (T1 – T6 - Seed treatment with —@ 10 g kg <sup>-1</sup> ) | Height (cm) | Increase (%) | Fresh weight (g) | Increase (%) | Dry weight (g) | Increase (%) |
|----------------------------------------------------------------------|-------------|--------------|------------------|--------------|----------------|--------------|
| T1 <i>P. fluorescens</i>                                             | 53.6        | 65.3         | 88.8             | 42.7         | 15.38          | 67.5         |
| T2 <i>B. pumilus</i>                                                 | 47.7        | 47.3         | 80.3             | 29.1         | 13.31          | 45.0         |
| T3 <i>B. subtilis</i>                                                | 50.1        | 54.5         | 85.6             | 37.6         | 14.85          | 61.8         |
| T4 <i>B. megaterium</i>                                              | 36.8        | 13.5         | 68.4             | 10.0         | 11.14          | 21.4         |
| T5 <i>P. putida</i>                                                  | 44.9        | 38.6         | 77.1             | 23.9         | 12.46          | 35.8         |
| T6 <i>B. amyloliquefaciens</i>                                       | 40.7        | 25.5         | 73.2             | 17.6         | 11.72          | 27.6         |
| T7 Carbofuran 3G @ 1kg a.i. ha <sup>-1</sup>                         | 51.3        | 58.2         | 86.4             | 38.9         | 14.71          | 60.2         |
| T8 Untreated control                                                 | 32.4        |              | 62.2             |              | 9.18           |              |
| SE (m) ±                                                             | 1.54        |              | 1.24             |              | 0.35           |              |
| CD <sub>(0.05)</sub>                                                 | 3.27        |              | 2.64             |              | 0.73           |              |

(36.2%), T5 (45.3%), T2 (48.5%), T3 (66.2%), T7 (71.8%), and T1 (79.8%). None of the treatments were statistically non-significant compared to the untreated check (T8).

A comparative analysis of the average dry root weight data revealed that the weights varied from 1.80g in T8 to 3.25g in T1. There was little difference in dry root weight amongst the treatments, even though all of them were noticeably superior to the untreated control (T8). T4 saw a 26.3% rise in dry root weight over the check, while T1 saw an 80.7% increase. Following T1 were, T7 (71.7%), T3 (52.4%), T2 (44.3%), T5 (38.1%), and T6 (34.4%). All treatments were statistically similar, except for T1. This treatment T1 was significantly different from all others, with the sole exception of T7, (Carbofuran 3G at a rate of 1kg a.i. ha<sup>-1</sup> (Table 3, Fig. 2, 3).

Siddiqui *et al.* (2009) similarly reported that *Bacillus* was less effective than *Pseudomonas* isolates in enhancing plant development and minimizing nematode damage in peas. Mishra *et al.* (2018) found that untreated controls affected by root-knot nematodes significantly increased the height, shoot weight, and root weight of okra when compared to

soil treatments containing *P. fluorescens*. Khan and Haque (2011) reported similar benefits in tobacco, while Nama and Sharma (2017), Singh *et al.* (2014), and Mohamed *et al.* (2009) found that *P. fluorescens* improved growth in cowpea, okra, and faba beans by reducing *Meloidogyne incognita* infestation. Bakker *et al.* (2003) reveal that *P. fluorescens*'s capacity to create hormones that regulate plant growth, including as gibberellins, auxins, and cytokinins, which enhance the absorption of nutrients and encourage sprouting of roots, is responsible for its growth-promoting properties. This, in turn, increases the plants' resistance to nematode attacks. More recently, Egan and Kakouli-Duarte (2022) confirmed that plant growth-promoting *P. fluorescens* strains suppress *M. javanica* development while simultaneously increasing host plant biomass, reinforcing the dual growth-promotion and biocontrol role observed in the present study.

#### **Impact of bacterial antagonists on root knot nematode growth on okra:**

In analysing the quantity of galls that root-knot nematodes produced per plant was estimated under which treatment T1 had the fewest galls (34.00),

significantly differing from all other treatments except T7 (43.33). The treatments in ascending order were T3 (50.00), T2 (61.67), T5 (69.33), T6 (76.33), and T4 (86.33). The application of *P. fluorescens* resulted in the most significant decrease in galls, (70.4% compared to the untreated control) followed by T7 (62.3%), T3 (56.5%) and T2 (46.4%). T5 (39.7%), T6 (33.6%) and T4 (24.9%) showed only lower reduction of galls. All treatments resulted in a significant drop in egg masses per plant. The most substantial decrease in egg masses (78.4%) was achieved with T1 compared to the check (89.33). This was followed by T7 (71.3%), T3 (64.2%), T2 (49.3%), T5 (41.8%), and T6 (37.3%) in descending order. T1 also recorded the lowest number of egg masses (19.33), followed by T7 (25.67) and T3 (32.00). T1 was significantly more effective than all other treatments, including the chemical check, while the treatments (T2, T5), (T5, T6), and (T6, T4) were statistically similar.

In the root-knot nematode population per 200cc of soil also T1 recorded least population (121.0),

followed by T7 (127.7), T3 (139.0), T2 (167.3), and T5 (185.3). The reduction in nematode population compared to the check (326.3) was highest in T1 (62.9%), followed by T7 (60.9%), T3 (57.4%), T2 (48.7%), T5 (43.2%), and T6 (41.3%). Compared to the untreated check (T8), T1 (such as the management of seeds using *P. fluorescens* @ 10g/kg of seeds) in order was the most effective treatment which was statistically similar to T7, and T5 was also similar to T6. The percentage decrease in nematode population per 200cc of soil ranged from 62.9 in T1 to 37.1 in T4 compared to the check. All treatments significantly reduced the number of root-knot nematodes compared to the baseline. Additionally, T8 had the maximum root-knot index (5.0), whereas T1 had the lowest (3.33), followed by T7 (3.67). The remaining treatments had a root-knot index of 4.0 (Table 4). Anwar-ul-Haq *et al.* (2011) found that *P. fluorescens* significantly improved plant growth in tomatoes by reducing nematode-related issues like females per root system and galls, performing better than *P. putida*, *Bacillus* spp., or PGPR combinations. Kadam and Khan (2015) similarly showed that treating okra

**Table 3. Impact of bacterial antagonists on root growth of root knot nematode infected okra**

| Treatments (T1 – T6 - Seed treatment with —@ 10 g kg <sup>-1</sup> ) | Length (cm) | Increase (%) | Fresh weight (g) | Increase (%) | Dry weight (g) | Increase (%) |
|----------------------------------------------------------------------|-------------|--------------|------------------|--------------|----------------|--------------|
| T1 <i>P. fluorescens</i>                                             | 23.1        | 76.6         | 18.74            | 79.8         | 3.25           | 80.7         |
| T2 <i>B. pumilus</i>                                                 | 18.2        | 38.8         | 15.48            | 48.5         | 2.60           | 44.3         |
| T3 <i>B. subtilis</i>                                                | 21.8        | 66.1         | 17.32            | 66.2         | 2.74           | 52.4         |
| T4 <i>B. megaterium</i>                                              | 15.2        | 16.4         | 13.70            | 31.5         | 2.27           | 26.3         |
| T5 <i>P. putida</i>                                                  | 17.1        | 30.4         | 15.14            | 45.3         | 2.49           | 38.1         |
| T6 <i>B. amyloliquefaciens</i>                                       | 15.8        | 20.6         | 14.19            | 36.2         | 2.42           | 34.4         |
| T7 Carbofuran 3G @ 1kg a.i. ha <sup>-1</sup>                         | 22.7        | 73.6         | 17.91            | 71.8         | 3.09           | 71.7         |
| T8 Untreated control                                                 | 13.1        |              | 10.42            |              | 1.80           |              |
| SE (m)±                                                              | 0.59        |              | 0.47             |              | 0.22           |              |
| CD <sub>(0.05)</sub>                                                 | 1.25        |              | 1.00             |              | 0.46           |              |

**Table 4. Impact of bacterial antagonists on root knot nematode growth in the infected okra**

| Treatments (T1 – T6 -<br>Seed treatment with — @ 10 g kg <sup>-1</sup> ) | Galls/<br>plant (no.) | Decrease<br>(%) | Egg mass/<br>plant (no.) | Decrease<br>(%) | Population/<br>200 cc soil | Decrease<br>(%) | RKI  |
|--------------------------------------------------------------------------|-----------------------|-----------------|--------------------------|-----------------|----------------------------|-----------------|------|
| T1 <i>P. fluorescens</i>                                                 | 34.00(5.79)           | 70.4            | 19.33(4.39)              | 78.4            | 121.0(11.00)               | 62.9            | 3.33 |
| T2 <i>B. pumilus</i>                                                     | 61.67(7.85)           | 46.4            | 45.33(6.73)              | 49.3            | 167.3(12.93)               | 48.7            | 4.00 |
| T3 <i>B. subtilis</i>                                                    | 50.00(7.07)           | 56.5            | 32.00(5.65)              | 64.2            | 139.0(11.79)               | 57.4            | 4.00 |
| T4 <i>B. megaterium</i>                                                  | 86.33(9.29)           | 24.9            | 63.00(7.93)              | 29.5            | 205.3(14.33)               | 37.1            | 4.00 |
| T5 <i>P. putida</i>                                                      | 69.33(8.32)           | 39.7            | 52.00(7.21)              | 41.8            | 185.3(13.61)               | 43.2            | 4.00 |
| T6 <i>B. amyloliquefaciens</i>                                           | 76.33(8.74)           | 33.6            | 56.00(7.48)              | 37.3            | 191.7(13.84)               | 41.3            | 4.00 |
| T7 Carbofuran 3G @ 1kg a.i. ha <sup>-1</sup>                             | 43.33(6.53)           | 62.3            | 25.67(5.06)              | 71.3            | 127.7(11.30)               | 60.9            | 3.67 |
| T8 Untreated control                                                     | 115.00(10.72)         |                 | 89.33(9.45)              |                 | 326.3(18.06)               |                 | 5.00 |
| SE (m) ±                                                                 | 0.44                  |                 | 0.23                     |                 | 0.16                       |                 | 0.24 |
| CD <sub>(0.05)</sub>                                                     | 0.92                  |                 | 0.48                     |                 | 0.34                       |                 | 0.50 |

Note: The values in parentheses are “(x + 0.5) transformed mean. RKI - Root-knot index was scored on a 0–5 scale

seeds with *P. fluorescens* (10g kg<sup>-1</sup>) effectively reduced root-knot nematode populations, while Mishra *et al.* (2017) found that tuberose had higher shoot weight and less gall development. Other studies, such as Kalairasan *et al.* (2008) and Abo-Elyousr *et al.* (2010), supported *P. fluorescens*’ effectiveness in lowering nematode populations and boosting plant resistance. This suppression is thought to occur through the production of nematode-inhibiting metabolites (Siddiqui and Shaukat, 2003), degradation of root exudates, and activation of systemic resistance (Jonathan and Umamaheswari, 2006). Enzymes like peroxidase, polyphenol oxidase, and chitinase also enhance plant defenses (Osman *et al.*, 2011), leading to fewer galls and improved plant growth. These findings are further corroborated by Stucky *et al.* (2023), who identified several *Pseudomonas* strains as reliable antagonists of *M. incognita*, and by Zhao *et al.* (2021), who showed that endophytic *Pseudomonas* and *Serratia* isolates significantly lowered root-knot nematode reproduction through similar antagonistic mechanisms.

### Association of galls/ plant and yield components:

Analysing correlations helps breeders understand the relationships between traits, providing insights for genetic improvement through selective breeding. Various economically important plant traits often display different interconnections. Significant positive correlations were observed between galls per plant and several factors, including egg mass per plant (0.998), nematode population (0.968) and root not index (0.907). In contrast, plant height (0.983), fresh shoot weight (0.988), dry shoot weight (0.990), root length (0.960), fresh root weight (0.996) and dry root weight (0.983) showed negative correlations that were statistically significant (Table 5).

The *P. fluorescens* based seed treatment achieved the lowest root knot index of 3.33, indicating relatively better performance in reducing nematode galls, egg masses, and larval population per 200 cc of soil, under pot experiment conditions with limited

**Table 5. Estimates of correlation coefficients among galls/plant and yield components in Okra**

|     | PH    | FSW     | DSW     | RL      | FRW     | DRW     | RNI      | EM       | NP       | GP       |
|-----|-------|---------|---------|---------|---------|---------|----------|----------|----------|----------|
| PH  | 1.000 | 0.997** | 0.986** | 0.959** | 0.972** | 0.955** | -0.829*  | -0.974** | -0.924** | -0.983** |
| FSW |       | 1.000   | 0.995** | 0.974** | 0.982** | 0.961** | -0.834*  | -0.984** | -0.934** | -0.988** |
| DSW |       |         | 1.000   | 0.978** | 0.989** | 0.960** | -0.848** | -0.990** | -0.947** | -0.990** |
| RL  |       |         |         | 1.000   | 0.968** | 0.956** | -0.795*  | -0.968** | -0.886** | -0.960** |
| FRW |       |         |         |         | 1.000   | 0.982** | -0.908** | -0.998** | -0.968** | -0.996** |
| DRW |       |         |         |         |         | 1.000   | -0.922** | -0.985** | -0.936** | -0.983** |
| RNI |       |         |         |         |         |         | 1.000    | 0.907**  | 0.936**  | 0.907**  |
| EM  |       |         |         |         |         |         |          | 1.000    | 0.969**  | 0.998**  |
| NP  |       |         |         |         |         |         |          |          | 1.000    | 0.968**  |
| GP  |       |         |         |         |         |         |          |          |          | 1.000    |

Note: PH = Plant height; FSW = Fresh shoot weight; DSW = Dry shoot weight; RL = Root length; FRW = Fresh root weight; DRW = Dry root weight; RNI = Root-knot index; EM = Egg mass/plant; NP = Nematode population/200 cc soil; GP = Galls/plant. \* = Significant at  $p < 0.05$ ; \*\* = Significant at  $p < 0.01$ .

replications. Additionally, it tended to improve plant height, both dry and fresh shoot weights, fresh and dry root weights, and a number of other growth metrics. Nevertheless, in most of the measured metrics, its performance was statistically similar to that the application of carbofuran 3G kg a.i.ha<sup>-1</sup> for combat with root knot nematode (*Meloidogyne incognita*) in okra. Treating seeds with the bacterial antagonist *P. fluorescens* appears promising. These preliminary findings, while encouraging, are based on a pot experiment with limited replications; field-level validation with adequate replications is warranted before firm recommendations can be made. The potential environmental benefits over chemical nematicides, including reduced residual toxicity, health hazards, and groundwater contamination, further support the need for continued investigation of this approach. As recently reviewed by Bhat *et al.* (2023), microbial antagonists such as *Pseudomonas* and *Bacillus* species continue to represent one of the most promising and sustainable alternatives to chemical

nematicides for the management of root-knot nematodes across a range of vegetable crops.

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