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RESEARCH ARTICLE

Study of endophytic and rhizobacteria against root rot pathogen *Macrophomina phaseolina* in sesame

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Abstract

Macrophomina phaseolina is one of destructive soil borne pathogens causing significant yield losses in oilseed crops such as groundnut, soybean and sesame. Bacterial endophytes isolated from sesame wild species were tested for their antagonistic against *Macrophomina phaseolina* and Plant Growth-Promoting Rhizobacteria (PGPR) activities in sesame. Totally twenty isolates were isolated from wild species and released varieties. Out of twenty entophytes isolated, three strains were showed maximum inhibition of *M. phaseolina* mycelial growth ranged from 44.31 to 46.59 %. The three isolates were identified as *Stenotrophomonas maltophila* (PP716377.1), *Bacillus stercoris* (PQ578246.1) and *Bacillus subtilis* (PQ57832.1) and submitted in National Center for Biotechnology Information (NCBI). Under pot culture experiment, *Bacillus stercoris* showed increased sesame seed germination (95.20 %), shoot (16.18 cm) and root length (4.0 cm) and vigour index (1921) compared to control. Further, the isolates were tested under field condition along with other biocontrol agents and chemicals during two consecutive season (*rabi*/summer 2023-2024 and *Kharif* 2024-2025) at Regional Research station, Vriddhachalam, Tamil Nadu Agricultural University, Tamil Nadu. Among the studied treatments during two seasons, the T4 - seed treatment (4 g/kg) and soil application *Trichoderma asperellum* + soil application *B. stercoris* (2.5 kg/ha) + soil drenching with carbendazim (1 g/L) on 30 and 45 days after sowing (DAS) recorded less disease incidence of 6.8 % and 7.2 % which accounted 70.18 and 74.91 % reduction of root rot over control respectively and also increasing yield 700 kg/ha and 678 kg/ha.

Keywords: disease management; endophytes; PGPR; root rot; wild sesame

Introduction

In India, recently West Bengal is highest production of sesame (2.2 lakh tons) followed by Madya Pradesh, it is grown from ancient times, popularly known as "Queen of oilseeds". In Tamil Nadu, sesame is cultivated in an area of 39087 ha with average productivity of 538 kg/ha. Sesame seeds and its oil are in high demand for export as sesame seeds are a good source of dietary protein. Its seed is used as sweets making and medicinal forms. In South India sesame oil used for cooking. Sesame ranked first among oil seed crops in oil content (50-52 %) with significant dietary energy (6335 kcal per kg), *Macrophomina phaseolina* is mainly a soil-borne pathogen with wide host range. *M. phaseolina* can infect the sesame plant at any stage of growth when temperature varies from 28° C to 32° C and germination of microsclerotia showed maximum growth at 30-33° C. In severe the diseased plants show blackening of capsules with immature and shriveled seeds. *Macrophomina phaseolina* is a generalist soil-borne fungus present all over the world. It causes diseases such as stem and root rot, charcoal rot. Under high temperatures and low soil moisture, this fungus can cause substantial yield losses in crops such as soybeans, sorghum and groundnut. The wide host range and high persistence of *M. phaseolina* in soil as microsclerotia make disease control challenging (1). Research priority was given to manage root rot disease. Integrated disease management (IDM) has emerged as the promising approach for management of root rot of sesame (2). Pathogen not only persists in soil as saprophyte associated with other soil microorganisms but also transmitted through seed.

At present chemical fungicides are the first choice for the farmers to combat diseases because of their easy adaptability and immediate therapy. Due to health risk and pollution hazards by use of chemical fungicides in plant disease control, it is considered appropriate to minimize their use. Since sesame seeds and oil are in high demand for export due to their high unsaturated fat and methionine content, focus has been shifted out safer alternatives to chemical fungicides in recent years. Biological control has attained importance in modern agriculture for disease control. Since the efficacy of biocontrol agents in disease abatement has been inconsistent due to their inability to maintain a critical threshold population necessary for sustained bio-control activity, biocontrol with antagonistic microorganism alone could not be a complete replacement for management strategies currently employed. The activities and population of introduced antagonist generally decline with time after their application and thus making the beneficial response of short duration, the seed treatment with two different bio agents like *Trichoderma viride* and *Pseudomonas flourescens* has shown minimum incidence disease with maximum yield i.e., T6 (seed treatment with *Trichoderma viride* @ 10 g/kg of seed + *Pseudomonas fluorescens* @ 10 g/kg of seed, furrow application of enriched *Trichoderma viride* (2.5 kg *Trichoderma viride* + 100 kg vermicompost) @ 250 kg/ha followed by two sprays of Nimbecidine @ 10mL/L at thinning, flowering and spray of Sulphur @ 2 g/L at capsule stage) has recorded minimum disease incidence against root and stem rot (8.33 %) and minimum per cent disease index (PDI) for Alternaria leaf spot (5.33 %) and Cercospora leaf spot (5.66 %) and gave the maximum yield of 615 kg/ha (3) hence, it requires different management approaches to overcome this menace. So, keeping in view the present investigations may be carried out for safe use of biocontrol and fungicides for disease management without caused hazardous effect.

Materials and Methods

Plant materials

The samples were collected from four wild species of sesame (*Sesame alatum*, *S. mulayanum, S. prostratum* and *S. radiatum*), released varieties of Swetha, VRI 1, VRI2, VRI 3, VRI 4, VRI 5, TMV 4, TMV7, TKG22 and Co1 and landraces of Kalavrayan hills, Pachamalai hills. These experimental materials were used for the study of endophytic and rhizobacteria antagonism against root rot pathogen *Macrophomina phaseolina* in sesame.

Sample preparation and bacterial isolation

The collected stems and roots were washed in running water. Each isolation procedure was done in triplicate for each cultivar. Each triplicate was composed of approximately 2 g of stems and roots belonging to two different plants being evaluated, the stems or roots were 70 % alcohol for 1 min, sodium hypochlorite (2.5 % Cl^-) for 4 min, ethanol for 30 sand finally 3 rinses in sterile, distilled water. To confirm the disinfection protocol, aliquots of the sterile water used in the final rinse were plated in 10 % TSA (1.5 g/L of triptone, 0.5 g/L of soy peptone, 1.5 g/L of NaCl, 15 g/L of agar, pH 7.3) at 28° C for 15 days and the plates are examined for the presence or absence of microorganism growth colony (4).

Screening on antagonistic bacteria under *in vitro* conditions

The bacterial isolates were tested for their inhibitory effect on growth of *Macrophomina phaseolina* by following the dual culture technique. The bacterial isolates were streaked on one side of the petri dish (1 cm away from the edge of the plate) on Potato Dextrose Agar (PDA) medium and a mycelial disc (8 mm diameter) of the five-day old *Macrophomina phaseolina* was placed on the opposite side of the petri dish perpendicular to the bacterial streak. The plates were incubated at room temperature (28 + 2 °C) for 4 days. After four days of incubation, the pathogen growth and inhibition zone were measured and expressed in cm (5).

Plant growth promotion

The sesame (VRI 2) seeds were socked in different biocontrol agents 10 mL/kg of seeds are mixed and seeds drying shade dried 10 min before sowing, treated seed along with untreated seed (control) of sesame was tested initially for germination and seedling quality parameters as per the standard procedures before sowing the seed in the pots. Five representative plants of each treatment were selected randomly and tagged for recording various observations *viz., seed germination, seedling length,* root length of seedlings and seedling vigour index as per the standard procedures (6).

Germination (%)

Germination occurs on the fifth day with two cotyledon leaves. On the day of final count (7th day), all the normal seedlings were counted. Based on the number of normal seedlings, the germination percentage from each sample in each replication was computed as per the formula mentioned here under:

$$\text{Germination (\%)} = \frac{\text{Number of Normal seedlings}}{\text{Total number of seed sown}} \text{ X } 100$$

Seedling length (cm)

Ten normal seedlings were taken from each replication at random on the 7th day and the seedling length was measured from tip of the primary leaf to the tip of the primary root with the help of the scale and mean seedling length was expressed in centimetres.

Seedling Vigour Index **=** Germination (%) ×Mean seedling length (cm) + root length (cm)

Field experiments

The field experiment consisting of 9 treatments endophytic bacteria and chemical for three replications was conducted at Regional Research Station, Vriddhachalam using the sesame variety VRI 2. The plot size for each treatment was 5 x 4 m. The disease incidence was recorded at 15 days intervals and the yield parameters, yield (kg/ha). Five representative plants of each treatment were selected randomly and tagged for recording various observations *viz., plant height at maturity (cm), No of branches, number of capsules per plant* were recorded and analyzed statistically. All the normal agronomic practices were followed as per the TNAU, Tamil Nadu recommendation.

Results

Screening of endophytic microorganism against *Macrophomina phaseolina*

Bacterial endophytes were isolated from different tissues of sesame variety and wild species of sesame. The efficacy of the endophytes against root rot pathogen (*Macrophomina phaseolina*) was assessed through *in vitro* screening. Among the 20 isolates, SIE 2 and SIE 16, SIE 17 were shown to be effective in inhibiting the mycelial growth of the pathogen by recording the percent inhibition of 46.59 % SIE 2 and SIE 17 these were onpar with each other and followed by 40.91 % (SIE 16) comparing control, respectively. Furthermore, the effective three isolates molecular confirmation with sending to Eurobins genomics Pvt Bangalore identified the sequence were submitted an NCBI (PP716377.1) as *Stenotrophomonas maltophila* (SIE2), *Bacillus subtilis* (PQ57832.1) (SIE 16) and *Bacillus stercoris* (PQ578246.1) (SIE 17) (Table 1).

Plant growth promotions character

Germination percentage

Among the various treatments, the highest germination percentage (95 %) was recorded with seed treatment with *Bacillus stercoris* and it was statistically at par with *Stenotrophomonas maltophila* (94 %) whereas least germination rhizosphere organism pontoe (88 %), the chemical carbendazim (82 %) comparing to untreated biocontrol agents (Fig. 1)

Shoot length

Among the various treatments, the increasing shoot length (16.68 cm) was recorded with seed treatment with *Bacillus stercoris* and followed by *Stenotrophomonas maltophila* (15.11 cm) whereas least little shoot length (10.2 cm) rhizosphere organism pontoe (Fig. 1)

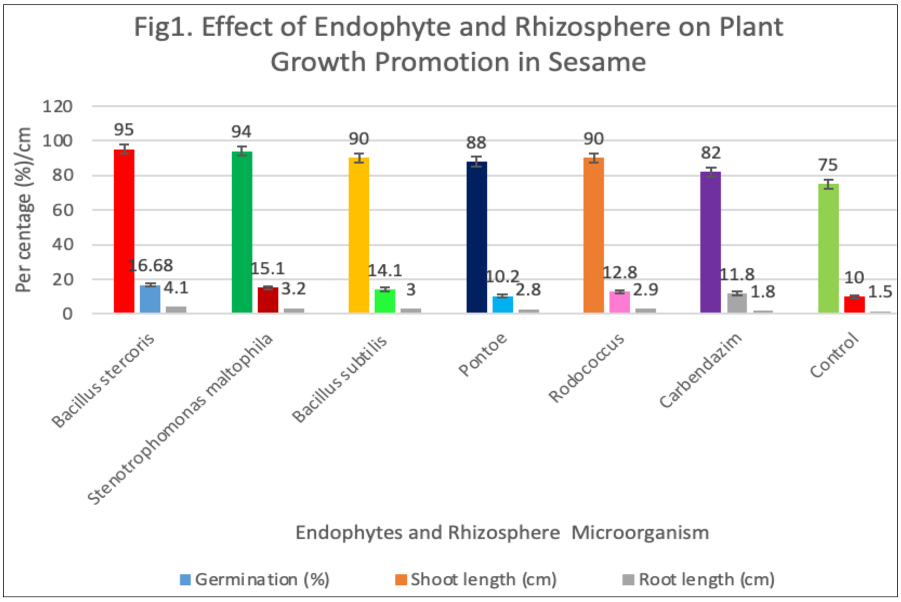

Fig. 1. Effect of endophytes on sesame plant growth promotion.

Table 1. Effect of endophytes and rhizosphere microorganism against *Macrophomina phaseolina* under *in vitro* conditions

Sl. No	Endophyte/ rhizosphere isolates	Plants used	Mycelial growth of *Macrophomina phaseolina* (cm)	Percent reduction over control (%)
1.	SIE 1	*Sesamum mulayanum*	7	20.45
2.	SIE 2	*Sesamum alatum* (Root)	4.7	46.59
3.	SIE 3	Swetha	5.3	39.77
4.	SIE 4	VRI 1	8.07	8.30
5.	SIE 5	VRI 2	5.3	39.77
6.	SIE 6	VRI 3	5.4	38.64
7.	SIE 7	VRI 4	5.3	39.77
8.	SIE 8	VRI 5	7.8	11.36
9.	SIE 9	TMV 4	8.2	6.82
10.	SIE 10	TMV 7 – Rhizosphere	5.3	39.77
11.	SIE 11	*Sesamum Prostratum*	5.4	38.64
12.	SIE 12	Kalvaran hills	8.3	5.68
13.	SIE 13	Pachamalai hills	8.3	5.68
14.	SIE 14	TKG 22	8.4	4.55
15	SIE 15	CO 1	8.3	5.68
16	SIR 16	*Sesamum radiatum* (Stem)	5.2	40.91
17	SIE 17	*Sesamum radiatum* (Root)	4.7	46.59
18	SIR 18	*Sesame alatum*	5.4	38.64
19	SIR 19	TMV 2	8.4	4.55
20	SIR 20	GT10	8.8	0.00
	Control		8.8	-
		C.D.	0.76	-
		SE(m)	0.26	-
		SE(d)	0.37	-
		C.V.	6.40	-

Root length

Among the various treatments, the increasing root length (4.1 cm) was recorded with seed treatment with *Bacillus stercoris* and followed by *Stenotrophomonas maltophila* (3.2 cm), whereas least little root length (2.8 cm) rhizosphere organism pontoe (Fig. 1)

Vigour index

Among the various treatments, the highest vigour index (1974.1) was recorded with seed treatment with *Bacillus stercoris* and followed by *Stenotrophomonas maltophila* (1720.2), whereas less vigour index for rhizosphere organism pontoe (1144) (Fig. 1)

Field experiments

Disease incidence (Rabi 2024)

The field experiment result revealed that, the lowest root rot disease incidence (6.8 %) recorded in the treatment viz., T4 ST (4 g/kg) and SA *Trichoderma asperellum* + SA *Bacillus stercoris* (2.5 kg/ha) + SD carbendazim (1 g/L) and followed by the chemical ST carbendazim (2 g/kg) + soil drenching carbendazim (1 g/L) (8.20 %) and ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Stentrophomonas maltophila* (2.5 kg/ha) + SD carbendazim (1 g/L) (8.4 %) these two treatments on par with each other (Table 2)

Plant growth character

The plant character changing the endophytic and rhizosphere microorganism in sesame among the different treatments, T4 ST (4 g/kg) and SA *Trichoderma asperellum* + SA *Bacillus stercoris* (2.5 kg/ha) + SD carbendazim (1 g/L) increasing plant height (132.36 cm), No. of branches (7.8 No), highest no of capsules per plant (124.62 Nos), highest no of seeds per capsule (60.68 Nos) and increasing yield (700 kg/ha) and followed by T46 ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Stentrophomonas maltophila* (2.5 kg/ha) + SD carbendazim (1 g/L) increasing plant height (128.44 cm), No. of branches (7.0 No), highest no of capsules per plant (120.42 Nos) highest no of seeds per capsule (58.20 Nos) and and increasing yield (610 kg/ha) also and comparing to other treatments (Table 2).

Disease incidence (Kharif 2024)

The field experiment result revealed that, the lowest root rot disease incidence (7.2 %) recorded in the treatment *viz*., T4 ST (4 g/kg) and SA *Trichoderma asperellum* + SA *Bacillus stercoris* (2.5 kg/ha) + SD carbendazim (1g/L) and followed by T6, ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Stentrophomonas maltophila* (2.5 kg/ha) + SD carbendazim (1 g/L) (9.6 %), T5 ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Bacillus subtilis* + (2.5 kg/ha) + SD carbendazim (1 g/L) (9.8 %), T3 ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Stentrophomonas maltophila* (2.5 kg/ha) (10 %) and in chemical ST carbendazim (2 g/kg) + soil drenching carbendazim (1 g/L) (10 %) these four treatments were on par with each other (Table 3)

Plant growth character

The plant character changing the endophytic microorganism in sesame among the different treatments, T4 ST(4 g/kg) and SA *Trichoderma asperellum* + SA *Bacillus stercoris* (2.5 kg/ha) + SD carbendazim (1 g/L) increasing plant height (122.84 cm), No.of branches (6.8 No), highest no of capsules per plant (110.56 Nos), highest no of seeds per capsule (54.68 Nos) and increasing yield (687 kg/ha) and followed by T6 ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Stentrophomonas maltophila* (2.5 kg/ha) + SD carbendazim (1 g/L) increasing plant height (116.23 cm), No. of branches (6.0 No), highest no of capsules per plant (104.18 Nos), highest no of seeds per capsule (50.1 Nos) and also increasing yield (587 kg/ha) and comparing to other treatments (Table 3)

Table 2. Effect of endophytic microorganism and fungicides against root rot of sesame (Rabi 2024)

. No	Treatment details	Root rot (%)	Percent reduction over control (%)	Plant height (cm)	No. of branches (Nos)	No. of capsule (Nos)	No. of seeds per capsule	Yield kg/ha
T1	ST (4 g/kg) and SA *Trichoderma asperellum* + SA *Bacillus stercoris* (2.5 kg/ha)	9.2	59.65	118.24	7.0	112.8	55.1	562
T2	ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Bacillus subtilis* +(2.5 kg/ha)	10.4	54.39	114.18	6.4	100.8	50.18	489
T3	ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Stentrophomonas maltophila* (2.5kg/ha)	9.8	57.02	116.8	6.8	110.12	52.6	563
T4	ST (4 g/kg) and SA *Trichoderma asperellum* + SA *Bacillus stercoris* (2.5 kg/ha)+ SD Carbendazim (1 g/L)	6.8	70.18	132.36	7.8	124.62	60.68	700
T5	ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Bacillus subtilis* +(2.5 kg/ha) + SD carbendazim (1 g/L)	8.6	62.28	124.62	6.8	114.8	56.8	577
T6	ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Stentrophomonas maltophila* (2.5 kg/ha) + SD carbendazim (1 g/L)	8.4	63.16	128.44	7.0	120.42	58.2	610
T7	ST (4 g/kg) and SA *Trichoderma asperellum*	8.9	60.96	110.2	6.4	100.2	50.12	517
T8	ST carbendazim (2 g/kg)+ soil drenching carbendazim (1 g/L)	8.2	64.04	108.4	5.8	92.6	48.3	567
T9	Untreated control	22.8	-	92	5.4	64.5	22.23	437
	C.D.	0.84		1.787	0.123	3.171	1.98	13.03
	SE (m)	0.27		0.591	0.041	1.049	0.655	4.31
	SE (d)	0.39		0.836	0.058	1.483	0.926	6.10
	C.V.	4.62		0.875	1.07	1.73	2.247	1.34

Table 3. Effect of endophytic microorganism and fungicides against root rot of sesame (Kharif 2024)

. No	Treatment details	Root rot (%)	Percent reduction over control	Plant height (cm)	No.of branches (Nos)	No. of capsule (Nos)	No. of seeds per capsule	Yield kg/ha
T1	ST (4 g/kg) and SA *Trichoderma asperellum* + SA *Bacillus stercoris* (2.5 kg/ha)	10.2	64.46	108.2	5.6	88.4	48.89	552
T2	ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Bacillus subtilis* + (2.5 kg/ha)	10.8	62.37	104.6	5.2	84.2	40.12	477
T3	ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Stentrophomonas maltophila* (2.5 kg/ha)	10	65.16	106.12	5.8	90.48	42.77	543
T4	ST (4 g/kg) and SA *Trichoderma asperellum* + SA *Bacillus stercoris* (2.5 kg/ha)+ SD carbendazim (1 g/L)	7.2	74.91	122.84	6.8	110.56	54.68	687
T5	ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Bacillus subtilis* + (2.5 kg/ha) + SD Carbendazim (1 g/L)	9.8	65.85	112.88	5.6	102.43	48.2	570
T6	ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Stentrophomonas maltophila* (2.5 kg/ha) + SD carbendazim (1 g/L)	9.6	66.55	116.23	6.0	104.18	50.1	587
T7	ST (4 g/kg) and SA *Trichoderma asperellum*	10.6	63.07	98.4	5.2	100.12	46.4	530
T8	ST carbendazim (2 g/kg)+ soil drenching carbendazim (1 g/L)	10	65.16	88.52	4.4	90.53	38.12	563
T9	Untreated control	28.7	-	85	3.1	42.14	15.3	430
	C.D.	1.16	-	2.168	0.184	3.499	2.01	12.451
	SE (m)	0.37	-	0.717	0.061	1.157	0.665	4.118
	SE (d)	0.52	-	1.014	0.086	1.636	0.94	5.823
	C.V.	5.39	-	1.186	1.985	2.219	2.694	1.3

Table 4. Effect of endophytes and rhizosphere microorganism against Macrophomina Phaseolina in sesame crops pooled two season data (Kharif and Rabi 2024)

S.No	Treatment details	Root rot (%)		Mean disease incidence	Percent reduction over control	Yield kg/ha		Mean yield kg/ha	B:C ratio
		Rabi 2024	*Kharif* 2024			*Rabi* 2024	*Kharif* 2024		
T1	ST (4 g/kg) and SA *Trichoderma asperellum* + SA *Bacillus stercoris* (2.5 kg/ha)	9.2	10.2	9.7	62.33	562	552	557	2.0
T2	ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Bacillus subtilis* + (2.5 kg/ha)	10.4	10.8	10.6	58.83	489	477	483	1.8
T3	ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Stentrophomonas maltophila* (2.5 kg/ha)	9.8	10	9.9	61.55	563	543	553	1.90
T4	ST (4 g/kg) and SA *Trichoderma asperellum* + SA *Bacillus stercoris* (2.5 kg/ha) + SD carbendazim (1 g/L)	6.8	7.2	7	72.82	700	687	693.5	2.90
T5	ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Bacillus subtilis* + (2.5 kg/ha) + SD carbendazim (1 g/L)	8.6	9.8	9.2	64.27	577	570	573.5	2.40
T6	ST (4 g/kg) and SA *Trichoderma asperellum* + SA of *Stentrophomonas maltophila* (2.5 kg/ha) + SD carbendazim (1 g/L)	8.4	9.6	9	65.05	610	587	598.5	2.60
T7	ST (4 g/kg) and SA *Trichoderma asperellum*	8.9	10.6	9.75	62.14	517	530	523.5	1.80
T8	ST carbendazim (2 g/kg) + soil drenching carbendazim (1 g/L)	8.2	10	9.1	64.66	567	563	565	2.0
T9	Untreated control	22.8	28.7	25.75	-	437	430	433.5	-

Discussion

Isolation

Bacterial endophytes promote the growth of host plants and enhance their resistance toward various pathogens and environmental stresses (7) endophytes (17 Nos) and rhizosphere (3 Nos) microorganism isolated form wild and variety of sesame these methods of isolation of endophytes is supported by (8).

Dual culture techniques

Among 20 isolates *Bacillus stercoris* (PQ578246.1) (SIE 17) and *Stenotrophomonas maltophila* (SIE2) maximum reduction of mycelial growth of *M.phaseolina* (46.71 %) in dual culture assay of under *in vitro* condition, the same results supported a new bacterial strain, *Bacillus stercoris* 92p, from the rhizosphere soil of banana. We evaluated its ability to suppress the growth of *N. musae* and other fungal pathogens that cause leaf spot disease in bananas (9). Previous reports indicated that *B. stercoris* exhibits significant biocontrol characteristics. *B. stercoris* LJBS06 was isolated from the rhizosphere soil of grapevines and it demonstrated broad-spectrum antifungal activity against multiple phytopathogens in previous research studies (10). *Streptomyces hirsutus* was effective reduced the linear growth of *M. phaseolina* by 70.83 % under *in vitro* conditions. *S. violaceoruber* and *S. hirsutus* have proven that they can be used to combat soil-borne diseases, as well as improve growth parameters and increase yields (11)

Plant growth promotion

Our isolates *Bacillus stercoris* was also increased seed germination (95.20 %), shoot (16.18 cm) and root length (4.0 cm) and vigour Index (1921) followed by chemicals, Same results supported by earlier work Endophytic bacteria are potential candidates to promote the growth of medicinal plants, such as to enhance root and shoot biomass and stimulate seed germination (12) Bacteria applied in biological fertilizer can improve plant nutrition and provide an environmentally sustainable means of improving the growth and yield of plants (13). Some chemicals also increased plant growth supported the plant growth promotion traits by (14) pots treated with carbendazim 12 % + mancozeb 63 % @ 0.2 % recorded highest seed germination (99.33 %), seedling length (17.37 cm), seedling vigour index-I (1725) and seedling vigour index-II (3.97) followed by *T. viride with 98.33 %, 16.75 cm, 1647 and 3.54*

Disease management

The two season (*Rabi* 2024 and *Kharif* 2024) seed treatment (4 g/kg) and soil application *Trichoderma asperellum* + soil application *B. stercoris* (2.5 kg/ha) + soil drenching with carbendazim (1 g/L) on 30 and 45 DAS (T4) recorded less disease incidence 6.8 % and 7.2 % which accounted for 70.18 % and 74.91 % reduction of root rot over control and also increasing yield 700 kg/ha and 678 kg/ha (Table 2, 3).

The pooled analysis results revealed that, the lowest root rot disease incidence (7.0 %) recorded in the treatment viz., ST(4 g/kg) and SA *Trichoderma asperellum* + SA *Bacillus stercoris* (2.5 kg/ha) + SD carbendazim (1 g/L) less disease incidence and 72.84 % disease reduction and increasing yield (693 k/ha) and highest returen of cost of BC ratio (2.9) (Table 4) and also increasing plant height, no of branches, hihest no of capsules per plant. The results supported by earlier scientific studies (15) The integrated disease management module consisting of seed treatment with *Trichoderma viride* @ 4 g/kg + *Pseudomonas fluorescens* @ 10 g/kg + soil application of *P. fluorescens* @ 2.5 kg/ha + *T. viride* 2.5 kg/ha enriched in 100 kg of FYM + neem cake @ 250 kg/ha effectively reduced the root rot incidence which recorded the minimum disease incidence (14.75 and 11.15 %) with higher yield of 648 and 651 kg/ha were recorded. Integrated treatment *viz.*, seed treatment with *Trichoderma viride* + *Pseudomonas fluorescens* @ 5 g/kg each + soil application of *P. fluorescens* @ 2.5 kg/ha + *T. viride* @ 2.5 kg/ha enriched in FYM + neem cake @ 250 kg/ha at the time of sowing resulted in minimum root rot incidence (13.0 %) and maximum percent reduction of disease over control (68.8 %) and yield (304 kg/ha) (16).

The seed treatment with *Trichoderma viride* @ 10 g/kg, furrow application of enriched *Trichoderma* (2.5 kg *Trichoderma viride* + 100 kg vermicomposting) @ 250 kg/ha and two sprays of combi-product (Tebuconazole 50 % + Trifloxystrobin 25 %) @ 0.5 g/L first between 30 to 35 DAS and second between 50 to 60 DAS substantially decreased both *Macrophomina* stem and root rot and *Alternaria* leaf spot and increased grain yield (17). Integrated management of stem and root rot disease (*M. phaseolina*) of sesame was conducted with seven treatments. The results revealed that minimum stem and root rot incidence (9.5 %) and maximum yield (557 kg/ha) with C: B ratio 2.40 in 2017, stem and root rot incidence (10.5 %) and maximum yield (545 kg/ha) with C: B ratio 2.33 in 2018 were recorded in the treatment of T6 (seed treatment with carbendazim @ 2 g/kg + soil drenching with carbendazim @ 1 g/L) (18). Among different earlier worker reported my research findings differed others, combined application of *Trichoderma asperellum* seed treatment (4 g) and Soil application + *T. asperellum* + *Bacillus subtilis* (2.5 kg/ha) followed by soil drenching with carbendazim on 30 and 45 DAS is effectively controlled the root rot of sesame and increasing yield highest return of benefit cost ratio (2.7)

Conclusion

Research on beneficial bacterial strains has been primarily limited to laboratory studies and future research should therefore focus more on field experiments and practical applications. The single application of biocontrol for less controlling of soil borne disease, the combined application seed treatment (4 g/kg) and soil application *Trichoderma asperellum* + soil application *Bacillus stercoris* (2.5 kg/ha) + soil drenching carbendazim (1 g/L) recorded the highest reduction of root rot of *Macrophomina phaseolina* in sesame and also increasing yield.

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Authors' contributions

MP conceptualized the idea and obtained the project form Tamil Nadu Agricultural University, initiated the lab studies and conducted most of the experiments. RR and SM performed the sequence analysis, VR and CH assisted the field experiments, RB carried out the formal analysis, KT conducted the statistical analysis JS and PI completed the methodology part, JS and MT reviewed the entire project.

Compliance with ethical standards

Conflict of interest: All authors declared no conflict of interest.

Ethical issues: None

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