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Screening of sesame genotypes against *Macrophomina* stem and root rot disease and exploring eco-friendly management strategies

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The study aimed to evaluate the sesame genotypes against *Macrophomina* stem and root rot and to explore eco-friendly management strategies using biocontrol agents and organic amendments. The genotypes were screened in sick plot at the Agricultural Research Station, Mandor, Jodhpur Rajasthan, and categorized based on disease incidence. Notably, 12 genotypes exhibited low disease incidence and high yield potential. Field experiments were also carried out during kharif seasons of 2022-2023 and 2023-2024 years with different eight treatments and three replications in randomized block design. The treatment combining seed treatment with *Trichoderma harzianum* @ 10 g kg^{-1} of seed – Furrow application of enriched *T. harzianum* (2.5 kg *Trichoderma* + 100 kg vermicompost) @ 250 kg ha^{-1} followed by Rhizosphere inoculation of *T. harzianum* at thinning, and spray at flowering and capsule stage @ 5g l^{-1} showed the lowest disease incidence (6.56%) with highest disease control (75.70%). This treatment also resulted ~2.6 fold and ~1.4 fold higher yield over the un-treated check and carbendazim like chemical pesticides, respectively. Maximum net return (¹ 45,480 ha^{-1}), and B:C ratio (3.33) were also recorded with the same treatment. This study highlights the effectiveness of integrated biocontrol strategies for managing *Macrophomina* stem and root rot, providing a sustainable approach for sesame cultivation.

Keywords : Disease incidence, *Macrophomina*, sesame, Stem and Root rot, *Trichodermaharzianum*

INTRODUCTION

Sesame (*Sesamum indicum* L.) is a vital oilseed crop known for its high dietary protein (20%) and oil content (50%), rich in oleic (47%) and linoleic acids (39%).Natural antioxidants like sesamin, sesamolin, and tocopherols enhance its oxidative stability (Wan *et al.* 2015).

Sesame oil serves various industries, including pharmaceuticals and insecticides (Mujtaba *et al.*2020).In 2022-23, India cultivated sesame over 1.52 million hectares, producing 0.802 million tonnes, with major contributions from Madhya Pradesh, Uttar Pradesh, Rajasthan, and West Bengal (Mathur *et al.* 2023).

Despite its potential, sesame productivity is hindered by poor management and susceptibility to stresses; particularly diseases like *Macrophomina* stem and root rot (Nanda *et al.* 2024). This disease, caused by *Macrophominaphaseolina*, thrives in warm climates and dry conditions, causing significant yield losses. The pathogen's resistant microsclerotia can persist for 2 to 15 years, germinating under high temperatures and low moisture, and invading the plant's vascular system (Pandey and Basandrai, 2021). Symptoms include stem lesions, wilting, chlorosis, and root blackening, often leading to plant death (Khamari *et al.* 2016).

Macrophomina phaseolina causes yield losses between 15% and 100%, presenting a global economic threat (Bandopadhyay *et al.* 2022). Conventional chemical fungicides, while common, pose environmental and health risks,

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contribute to pathogen resistance, and harm ecosystem biodiversity (Imran *et al.* 2021). They can also impair crop physiology, particularly photosynthesis (Junqueira *et al.* 2021).

This study addresses the gap in evaluating sesame genotypes for disease resistance and eco-friendly management practices. We hypothesized that integrated management using *Trichoderma harzianum* through seed treatment, furrow application, rhizosphere inoculation, and foliar sprays would improve disease control and yield. The research aims to screen sesame genotypes for resistance to*Macrophomina* stem and root rot and to assess integrated management strategies involving biocontrol agents and organic amendments. Unlike studies focused on chemical or cultural controls, this research promotes a sustainable approach by combining genetic resistance and biological control, offering a comprehensive solution for managing *Macrophomina* stem and root rot in sesame cultivation.

MATERIALS AND METHODS

Genotypes screening for disease resistance

Collection of sesame genotypes

A collection of 176 genotypes, encompassing germplasm lines, IVT, AVT, and promising lines of sesame, were obtained from the Project Coordinating Unit, AICRP on Sesame in Jabalpur. These genotypes were assessed to determine their relative resistance or susceptibility to *Macrophomina* stem and root rot disease.

Field Experiment for screening

The experiment was conducted under sick plot conditions at the Agricultural Research Station in Mandor, Jodhpur, Rajasthan, India, during the kharif season of 2022. A sick plot for stem and root rot has been maintained for the past 15-20 years, with the inoculum density of *Macrophominaphaseolina* maintained at 100-150 microsclerotia per gram of soil or $2x10^3$ CFU/g of soil. The test genotypes were sown in a completely randomized block design with three replications, each in 3-meter row lengths with a spacing of 30 cm between rows and 10 cm between plants. The sowing took place in the first fortnight of July, and irrigation schedules, fertilizer applications, and plant protection measures against insect pests were carried out as per recommended agricultural practices for sesame production.

Data collection

The incidence of the disease was recorded by counting the number of infected plants and the total number of plants. The percent disease incidence (PDI) was calculated using the following formula, with minor modifications from Iram *et al.* (2003):

$$\text{Per cent Disease Incidence} = \frac{\text{Number of plants infected}}{\text{Total number of plants}} \times 100 \qquad (1)$$

All the genotypes were categorized in different categories of rating scale- 0 (no incidence), 1 (1-10% incidence), 2 (11-25% incidence), 3 (26-50% incidence), 4 (51-70% incidence) and 5 (more than 70% incidence)(Table 1).

Management of Macrophomina stem and root rot disease

Organic amendments

Nimbicideine 1500 ppm was used at a concentration of 4 ml per liter as a spray. Sulfur: Sulfur 80% WG was used at a concentration of 2 g per liter as a spray.

Chemical pesticides

Carbendazim was used as a seed treatment at a concentration of 3 g/kg. Tebuconazole 50% + Trifloxystrobin 25% was applied at a concentration of 0.5 g per liter for spraying. Carbendazim 12% + Mancozeb 63% was employed at a concentration of 2 g per liter for seed treatment and spraying.

Bioagents

Talc-based formulations of *Trichoderma harzianum*and *Pseudomonas fluorescens*were used. To enrich the vermicompost, a talc-based formulation was mixed with the vermicompost at a ratio of 1 kg of the formulation to 40 kg of vermicompost. The mixture was then kept in a shaded area for 15 days. During this period, the compost was regularly turned to facilitate aeration and enhance the enrichment process.

Treatment and methods of application

All treatments were given as per the following combinations: **T1**- Seed treatment (ST) with *Trichoderma harzianum* @ 10 g/kg of seed – Furrow application of enriched *T. harzianum* (2.5 kg *Trichoderma* + 100 kg vermicompost) @ 250 kg/ha followed by spray of *T. harzianum* at Thinning, flowering and capsule stage @ 5g/l; **T2**-ST with *Pseudomonas fluorescens* @ 10 g/kg of seed – Furrow application of enriched *P. fluorescens* (2.5 kg *P. fluorescens* + 100kg vermicompost) @ 250 kg/ha followed by spray of *P. fluorescens* at Thinning, flowering and capsule stage @ 5g/l; **T3**-ST with *T. harzianum* @ 10 g/kg of seed – Furrow application of enriched *T. harzianum* (2.5 kg *Trichoderma* + 100kg vermicompost) @ 250 kg/ha followed by Rhizosphere inoculation (by drenching) of *T. harzianum* at Thinning, and spray at flowering and capsule stage @ 5g/l; **T4**-ST with *Pseudomonas fluorescens* @ 10 g/kg of seed – Furrow application of enriched *P. fluorescens* (2.5 kg *P. fluorescens* + 100kg vermicompost) @ 250 kg/ha - Rhizosphere inoculation (by drenching using spray nozzle) of *P. fluorescens* at Thinning and spray at flowering and capsule stage @ 5g/l; **T5**-ST with *T. harzianum* @ 10 g/kg of seed – Furrow application of enriched *T. harzianum* (2.5 kg *Trichoderma* + 100kg vermicompost) @ 250 kg/ha followed by spray of Nimbecidine 1500ppm @ 4ml/l at Thinning, flowering and spray of sulphur 80% WG @ 2g/l at capsule stage;**T6**-ST with Carbendazim @ 3g/kg – spray of (Tebuconazole 50% + Trifloxystrobin 25%) at 0.5g/l at 45 and 60 days after sowing. (treated check); **T7**-ST with Carbendazim @ 3g/kg – spray of (Carbendazim 12 % + Mancozeb 63 %) at 2g/l at 45 and 60 days after sowing. (treated check); **T8**-Untreated check.

For the experiment, various methods were utilized to apply biocontrol agents and other treatments. For seed treatment, 10 grams of the biocontrol agent formulation were used to treat 1 kg of seeds. In the furrow application, 2.5 kg of separate formulations of *T. harzianum* and *P. fluorescens* were mixed with 100 kg of vermicompost and applied at a rate of 250 kg per hectare. Rhizosphere inoculation was conducted by drenching with a spray nozzle during thinning, using a solution at a concentration of 5 g/l. Additionally, spraying was performed at the flowering and capsule stages, also at a concentration of 5 g/l. Nimbecidine was applied at a concentration of 4 mL/l during the thinning and flowering stages, while sulfur was sprayed at a concentration of 2 g/l during the capsule stage.

Field experiment for ecofriendly management of Macrophomina root root

A field experiment was conducted during the kharif seasons of 2022-2023 and 2023-2024 at the Agricultural Research Station, Mandor, Jodhpur, Rajasthan, India, to evaluate the efficacy of various biocontrol agents in combination with organic treatments on disease incidence and yield of sesame. The experimental site is located at approximately 26.3056° N latitude and 73.0126° E longitude.The experiment was designed as a randomized block design with three replications, encompassing eight distinct treatments.Sesame seeds were treated with the selected biocontrol agents at a rate of 10 g/kg of seeds using a talc-based formulation. In contrast, control seeds were treated with a suspension of blank talc powder. Prior to treatment, the sesame seeds were surface sterilized by soaking them in 70% ethanol for 1 minute, followed by a 5-minute soak in a 1.5% sodium hypochlorite solution. After treatment, the seeds were allowed to air dry for 2 hours to remove excess moisture while ensuring that the biocontrol agents remained firmly attached to the seed surface.

The variety RT 351 was used for this experiment. Seeds were manually sown, adhering to a row spacing of 30 cm and a plant-to-plant distance of 10 cm, with each plot measuring 3 m x 4 m. The seed rate employed was 2-2.5 kg/ha. The recommended fertilizer dosage, comprising 40 kg of N and 25 kg of P, O… per hectare, was applied using urea and DAP. The full dose of phosphorus and half the dose of nitrogen were applied as a basal dose at the time of sowing, with the remaining nitrogen applied 30 days after sowing (DAS). The two biocontrol agents, *T. harzianum* and *P. fluorescens*, were applied using different methods and in combination with nimbecidine and sulfur, and were compared against treated and untreated controls.

The incidence of *Macrophomina* stem and root rot was recorded by counting the infected plants in randomly selected quadrants within each plot, replication-wise. PDI was calculated based on the number of infected and total plants. Percent disease control wascalculated by using following formula:

$$\text{Disease Control \%} = \frac{\text{Disease incidence in control \%} - \text{Disease incidence in treatment \%}}{\text{Disease incidence in control \%}} \times 100 \quad (3)$$

Observations on yield were recorded in kg/ha at harvest. The weekly agro-meteorological parameters for the years 2022–2023 and 2023–2024 are presented in charts (Fig.1).

Economics

The cost of cultivation for the different treatments was calculated based on the inputs used and their prevailing costs. Gross returns (□/ha) were determined by considering the seed/grain and plant part/straw yield along with their current market prices. These values were then utilized to calculate the net return (□/ha). The benefit-to-cost ratio was determined by dividing the gross return by the cost of cultivation.

Statistical analysis

All the data obtained from the experiment were used to analyze the mean values of three replications for each treatment. The data were then statistically analyzed using OPSTAT and Minitab 17 statistical software, employing one-way analysis of variance (ANOVA). Grouping of the mean values from the obtained data of each experiment was performed using Fisher's LSD method at a 95% confidence level (P d" 0.05).

RESULTS AND DISCUSSION

Genotypes screening for Macrophomina root rot disease resistance

The screening of various sesame genotypes against *Macrophomina* stem and root rot infection revealed significant variability in disease incidence and pathogenic reactions (Tables 2). Among the tested genotypes, RT-396, AT-494, RT-398, AT-488, SVT-464, RT-392, AT-467, MT-2019-7, GKVKS-1, DS-61, PR-1039, and KRR-1 exhibited strong resistance with disease incidence ranging from 6.67% to 9.73%. Moderately resistant

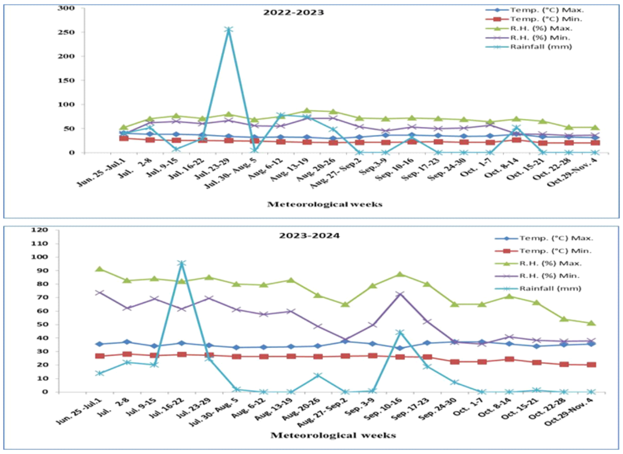

Fig 1: Weekly meteorological parameters during the kharif seasons of 2022–2023 and 2023–2024.

genotypes included GT-10, VS 20-040, JLS-1411-5-5, PCU-21-1, VS-19-036, TLT-10, SVT-460, IS-319-B, KMR-49, SP-184-A, IS-191, SI-958-23, S-0314, IS-16-A, KMR-30-B, and S-0351, showing disease incidences between 15.28% and 25.00%.On the other hand, one genotype, S-0268, was identified as highly susceptible, presenting the highest disease incidence at 80.0%.The root-rot resulting due to concomitant infection by *M. phaseolina* is a devastating disease and causes significant reduction in the plant yield (Ikram and Dawar 2013). Ezhilarasi and Meena (2019) found that out of 24 breeding lines, only two (VS 16 004 and VS 16 008) showed low disease incidence. Similarly, Manjeet *et al.* (2020) evaluated 24 genotypes and reported that only four (JLS 110-12, HT 9913, T 78, and KMR 60) had multiple disease resistances with disease incidence ranging from 0% to 8.80%. Farooq *et al.* (2019) assessed 26 sesame lines and found variability in response to *M. phaseolina*, with line 87008 exhibiting 1-10% mortality and lines 87502 and 95002 being moderately resistant, while TH6 and line 40009 showed high susceptibility.

Management of Macrophomina stem and root rot disease

All the biological treatments showed significant effect on controlling the *Macrophomina* compared

Table : 1 Disease rating scale for*Macrophomina* stem and root rot

Disease scale	Percent disease incidence (%)	Reaction
0	No incidence	Immune
1	1-10% incidence	Resistant
2	11-25% incidence	Moderately Resistant
3	26-50% incidence	Moderately Susceptible
4	51-70% incidence	Susceptible
5	More than 70% incidence	Highly susceptible

to chemical treatments as well as untreated check. Among the treatments, T3, which involved seed treatment with *Trichoderma harzianum* at 10 g/kg of seed, furrow application of enriched *T. harzianum* (2.5 kg *Trichoderma* + 100 kg vermicompost) at 250 kg/ha, followed by rhizosphere inoculation by drenching at thinning, and spray at flowering and capsule stages at 5 g/l, showed the lowest pooled disease incidence of 6.56% and the highest percent disease control of 75.70% over the untreated check. This integrated approach benefits from the synergistic effects of multiple *T. harzianum* application methods. Seed treatment ensures early protection against pathogens, while furrow application delivers sustained benefits through soil interaction (Table 3).

Chemical treatments T6 and T7, which included seed treatment with Carbendazim followed by sprays of Tebuconazole 50% + Trifloxystrobin 25% or Carbendazim 12% + Mancozeb 63% respectively, had pooled disease incidences of 10.22% and 12.37%, with percent disease control of 62.13% and 54.16%, respectively.On the other hand, T5, which involved seed treatment with *T. harzianum*, furrow application of enriched *T. harzianum*, and subsequent sprays of Nimbecidine and sulphur, resulted in a higher pooled disease incidence of 18.39% and lower disease control of 31.87%.

Our results are corroborated with Khan *et al.* (2019) who investigated that soil application of *Trichoderma viride* or *Trichoderma harzianum* was more effective in managing root-rot disease and enhancing mungbean yield as compared to carbendazim. The fungicide carbendazim has been reported quite effective against root-rot fungi (Shahid and Khan 2016). Lakhran and Ahir (2020) observed that treatments with *Trichoderma viride*, neem cake, and carbendazim were effective against chickpea dry root rot caused by *Macrophomina phaseolina*. *Trichoderma harzianum* applied to the rhizosphere can colonize the root surface more effectively, leading to a more persistent and stable population of beneficial microbes compared to foliar sprays which can be washed off or degraded by UV light (Harman *et al.* 2004). Rhizosphere application allows *Trichoderma* to establish itself in the root zone, which is rich in nutrients, promoting its colonization and persistence. This leads to prolonged activity against soil-borne pathogens (Woo *et al.* 2014). *Trichoderma harzianum* applied to the rhizosphere can induce systemic resistance in plants, enhancing their ability to resist various pathogens. This systemic effect is more pronounced with soil application compared to foliar sprays (Shoresh *et al.* 2010).

In present study, applying *Trichoderma* as a seed treatment, rhizosphere inoculation, and foliar spray for controlling *Macrophominaphaseolina* in sesame was found to be more effective than using *Pseudomonas fluorescens* through the same application methods. *Trichoderma* spp. are known for their multifaceted biocontrol mechanisms, including mycoparasitism, competition for nutrients and space, and the production of antibiotics and hydrolytic enzymes, which directly inhibit the growth of pathogens (Sood *et al.* 2020). In contrast, while *Pseudomonas fluorescens* is also effective as a biocontrol agent, its primary mechanisms involve competition for iron through siderophore

Table 2: Categorization of genotypes on the basis of their reaction against *Macrophominaphaseolina* in sesame

Levels	PDI values (%)	No. of genotypes	Genotypes	Category
0	No incidence	-	-	Immune
1	1-10% incidence	12	RT-396, AT -494, RT-398, AT -488, SVT-464, RT -392, AT-467, MT -2019-7, GKVKS -1, DS -61, PR -1039, KRR-1	Resistant
2	11-25% incidence	51	GT-10, VS 20 -040, JLS-1411-5-5, PCU -21-1, VS-19-036, PCU -21-2, SVT-460, TLT -10, RT -386, SKT -1501, CUMS -17, VRI -10, IC -131943, IS -319-B, SP -184-A, KIS -380, IS -191, SI -958-23, EC -303433-1, RJS-82-A, NIC-8439-A, SI -2630-A, IS-16-A, ES-36-B, Nirmala, RT -390, SEL -S-20-2001, OSC -79-13-3, PR -2102, PT-1019, JCS- 3794, IS-722-1, KMR-49, KMR-30-B, NIC -16289, NIC -16241, KMR -23, NIC -8439-B, IS-723-A, EC -303423-A, KMR -30-A, SI -3315, IS -3197-A, NIC -16327, NIC -16327-A, NIC -8224-A, IC -1025-A, NIC -8423-A, S -0484, IC -132186-A, IC -204550	Moderately Resistant
3	26-50% incidence	103	PCU-22-1, RT -397, VS 20 -001, VS 20 -008, TKG-22, IIOS-1103, IIOS-1104, JTS-8, VRI-1, AT -394, AT -457, RT-395, TKG -2021-3, VS -19-064, TLT -12, TLT -06, LT -15-26, RT-346, RT -387, DS -62, DSM-17-1-1, DSS-9, Smarak, VS17012, S16009, VS19023, RT -391, RT -389, OSM-19-07, Shubhra, PR-3003, PR -1038, PT-1030, JCS-3287, *S. radiatum* , 75 -120, SI -3257, KMR -53, IS -1672, SI -3274, IS -3051, IC -204200, S -0314, NIC -16256, IS -265-B, NIC -17452, NAL/78/3041431/2, S -0292, NIC -8463, IS -245, KMR-79-B, TC -30, SI -1004-B, S -0351, NIC -8502, KIS -306, EC-334976, ES -47, NIC -8164, NIC -17930, K -2, IS -112-B, B -240, IC -43102, N -66-39, JT -66-177, NSS, NIC-16219-A, 03 -Oct, S -0445, S -0392, S -0636, NIC -6292, IS -723-B, KMR-32-A, IC -423, GRT-8357, KMS-4294-A, IS -56-A, NIC -16278-A, NIC -17690-B, KMR -19, IS -129, SI -1865-1-A, KMR -80, SI -8008-A, KMR -32-B, KMR -4-259-A, KMS -423, GRT -8628, NIC-8538-A, IS -56-B, NIC -17890-A, ES -36-A, IS -731, SI -3273-A, NIC -16190-A, IS -255-2-84-A, KMR -74, KMR -48-A, S-0242, NIC-16387-A, GRT-8330-B	Moderately Susceptible
4	51-70% incidence	9	TLT -5-2, DSM -3-1, IS -646-2-84, GRT -8623, NIC -16439, RJS-350, KMS-5-380, SI-3100, GRT-839-A	Susceptible
5	More than 70% incidence	1	S-0268	Highly Susceptible

Table 3: Ecofriendly Management of *Macrophomina* stem and root rot disease

Tr. No.	MSRR (% incidence) 2022-23	2023-24	Pooled	Percent disease control over untreated check
T_1	8.82 (17.25)*	8.39 (16.80)	8.60 (17.03)	68.13
T_2	15.27 (22.95)	15.70 (23.31)	15.48 (23.14)	42.65
T_3	6.67 (14.93)	6.45 (14.66)	6.56 (14.79)	75.70
T_4	13.55 (21.55)	13.12 (21.21)	13.33 (21.38)	50.61
T_5	18.71 (25.61)	18.06 (25.12)	18.39 (25.37)	31.87
T_6	10.11 (18.51)	10.32 (18.71)	10.22 (18.61)	62.13
T_7	12.04 (20.26)	12.69 (20.84)	12.37 (20.55)	54.16
T_8	26.45 (30.92)	27.53 (31.63)	26.99 (31.28)	-
SEm ±	0.876	0.76	0.75	-
CD at 5%	2.682	2.33	2.30	-

* Data are the average value of three replicates and Figures in parenthesis indicate angular transformation values. Details of treatments provided in Materials & Methods

production and the secretion of antimicrobial compounds. However, it may not persist as long in the soil as *Trichoderma*, which can establish more robust and durable colonies in the rhizosphere (Singh *et al.* 2021).

Seed Yield

The biological management of *Macrophomina* stem and root rot disease through organic treatments was evaluated for its impact on seed yield in sesame over the years 2022-23 and 2023-24. The results, as detailed in Table 5, indicate significant variations in seed yield among the different treatments. All the biological treatments showed significant effect on yield compared to chemical treatments as well as untreated check. The highest pooled seed yield was observed in treatment T3 which was significant over the all treatments. This treatment resulted in a pooled seed yield of 794 kg/ha.Chemical treatment, involving seed treatment with Carbendazim and subsequent sprays of (Tebuconazole 50% + Trifloxystrobin 25%), resulted in a pooled yield of 606 kg/ha. Similarly, T7, which used Carbendazim and sprays of (Carbendazim 12% + Mancozeb 63%), showed a pooled yield of 545 kg/ha.

Table 4 : Evaluation of economics of different treatments used for management of stem & root rot in sesame

	Seed yield (kg/ha)			Gross return			Net return			B:C Ratio		
Tr. No.	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_1	731	710	721	57263	61337	59300	39403	39477	39440	3.21	2.81	3.01
T_2	413	399	406	32312	34482	33397	15072	13242	14157	1.87	1.62	1.75
T_3	823	766	794	64415	66144	65280	46615	44344	45480	3.62	3.03	3.33
T_4	464	458	461	36357	39520	37939	17593	16756	17175	1.94	1.74	1.84
T_5	382	365	373	29885	31518	30702	13590	11223	12407	1.83	1.55	1.69
T_6	609	603	606	47711	52098	49905	29615	30002	29809	2.64	2.36	2.50
T_7	548	541	545	42908	46744	44826	24708	24544	24626	2.36	2.11	2.24
T_8	305	290	298	23882	25042	24462	7882	5042	6462	1.49	1.25	1.37
SEm ±	17.31	13.78	14.30	1,355	1190	1272	1,355	1190	1272	-	-	-
CD at 5%	53.0	42.21	47.79	4,149	3645	3897	4,149	3645	3897	-	-	-

* Data are the average value of three replicates
Details of treatments provided in Materials & Methods

Rhizosphere inoculation enhances root health and nutrient uptake, and foliar spraying provides additional protection during key growth phases. The result is a robust defense against disease and an increase in crop productivity. *Trichoderma* spp. in the rhizosphere enhances soil health by decomposing organic matter and solubilizing phosphates and micronutrients, making them more available to plants. This leads to better root development and nutrient uptake consequently enhance the crop yield (Brotman *et al.* 2013). Kumar *et al.* (2023) reported a substantial decrease in disease incidence and an increase in crop yield when *Trichoderma* was applied using multiple methods.Our results are also corroborated with El-Bramawy *et al.* (2012) who reported that inoculation of *Trichoderma* significantly enhanced yield and yield component of sesame.

Economics

The economic evaluation of different treatments for managing stem and root rot in sesame reveals significant differences in their profitability and effectiveness (Table 4). Treatment T3, yielded the highest gross returns, net returns, and benefit-cost (B:C) ratio across all evaluated periods. The B:C ratio was notably high at 3.62, 3.03, and 3.33 for the respective years and pooled data. For the treatment T1, the B:Cratio was 3.21 and 2.81 for the respective years.In contrast, *Pseudomonas fluorescens* treatments-T2 and T4 resulted in a lower gross return, net return and B:C ratio. The chemical treatments (T6 and T7) provided moderate economic returns. On the chemical control front, the treatment involving Carbendazim combined with Tebuconazole and Trifloxystrobin (T6) generated a net return of ¹ 29,809, with a B:C ratio of 2.50. This method showed good economic performance over the untreated check but did not surpass the T3 biological control in terms of profitability. Another chemical treatment with Carbendazim and Mancozeb (T7) provided a a net return of ¹ 24,626, with a B:C ratio of 2.24. While effective over the untreated check, it was also less profitable compared to the T3 biological control treatment. Studies by Cuevas *et al.* (2011) in the Philippines showed that using *Trichoderma* spp. for controlling clubroot disease in crucifers could significantly boost farmers' income. Present results are also aligned with the study of Launio*et al.* (2020) who reported that the use of *Trichoderma koningii* strain KA increased net returns by reducing the incidence of clubroot disease in crucifers, leading to higher yields and reduced reliance on chemical pesticides.

These results highlight the potential of *T. harzianum* as a superior biological control agent and suggest that its use in conjunction with resistant genotypes offers a sustainable and effective strategy for managing *Macrophomina* stem and root rot in sesame. The findings support the adoption of integrated disease management practices to improve crop resilience and economic outcomes in sesame cultivation.

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DECLARATION

Conflict of Interest. Authors declare no conflict of interest.

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