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Integrated Management of Stem Rot of Groundnut Caused by *Sclerotium rolfsii*. sacc

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ABSTRACT

Background: Groundnut is the principal vegetable oil crop in India and about 85 per cent groundnut area under remains rain fed. Stem rot of groundnut is more prevalent in the area and is capable of causing considerable loss in the yield when left unmanaged.

Methods: In order to find out an effective method of managing the disease, an integrated approach was adopted by combining the use of bio agents, organic amendments and fungicides alone and in combinations.

Result: Seed treatment with tebuconazole @ 1 g kg^{-1} and with commercial formulation of *Trichoderma harzianum* @ 5g kg^{-1} seed along with soil application of neem cake @ 1.3 t ha^{-1} maintained its superiority over other treatments by recording the least PDI, maximum germination percentage (98.20%), root length (14.62 cm), shoot length (35.54 cm), number of pods per plant (32.57) and pod yield (3920.0 kg ha^{-1}) which may be synergistic effect of organic amendment with bioagent. However, all the sole treatments also managed the disease to some extent but greater control was recorded in combination treatments than alone.

Key words: Fungicides, Groundnut, Organic amendments, *S. rolfsii,* Stem rot.

INTRODUCTION

Groundnut (*Arachis hypogea* L.) is one of the most important oilseed crop in the world and the largest producer being China followed by India, Nigeria and United States (Groundnut Outlook, Agricultural Market Intelligence Centre, PJTSAU, 2019). Groundnut crop is affected with various diseases caused by fungi, bacteria, nematodes and viruses which reduce the pod yield of groundnut and also the fodder quality of haulm. Among the fungal diseases, stem rot caused by *Sclerotium rolfsii* Sacc, is one of the major constraints in groundnut production as it severely affects the yield and quality of the produce. It is one of the most economically important diseases of groundnut which accounts for 10 to 25 per cent loss in yield annually (Sturgeon, 1986). It was first observed by Peter Henry Rolfs in the year 1892 on tomato plants with 70% losses. The hyphae grew upward on the surface of the infected plant covered with a cottony, white mass of mycelium, scattered inside and outside of infected stem nearby the soil surface, The fungus produced numerous small round, white sclerotia of uniform size when immature and dark brown at mature stage (Kwon and Park, 2002). In India, stem rot incidence is most severe in Maharashtra, Gujarat, Madhya Pradesh, Karnataka andhra Pradesh, Odisha and Tamil Nadu, This disease causes severe damage and can reach over 80% in heavily infected fields (Mehan and McDonald, 1990).

The management of seed and soil-borne diseases only by seed treatment has been practical as soil application of chemicals has not only been expensive but also not practical. Thus other alternative disease management options were considered and among which biological control appear promising and have been considered as environmentally safe and virtuous supplement to the synthetic fungicides (Abada and Ahmad, 2014; Sohaliya *et al*., 2019). Various reports show the widespread application of *Trichoderma* spp. such as *T. asperellum, T. atroviride, T. gamsii, T. hamatum, T. harzianum, T. polysporum, T. virens* and *T. koningii* as bio control agents effective against various soil-borne pathogens such as *Phytophthora, Pythium, Aspergillus, Fusarium* and *Rhizoctonia* [(Moosa *et al*., 2017; Javaid *et al*., 2018; Sharma and Prasad 2018; Ingale and Patale (2019)] and organic amendments to suppress soil borne pathogens (Bonanomi *et al*., 2018). Several studies also suggest that when the bacterial or fungal antagonists such as *P. flourescens* or *Trichoderma* spp. were used in combination with organic amendments, their antagonistic efficacy was enhanced (Karthikeyan *et al*., 2006; Vengadeshkumar *et al*., 2019; Jangir *et al*., 2020). Organic amendments induce the association of beneficial micro flora around the rhizosphere, which can be of help to reduce the plant pathogens in the soil (Tayyab *et al*., 2019). Therefore, an attempt was made

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to identify the best biocontrol agent for the management of *Sclerotium rolfsii* the causal agent of stem rot of groundnut by evaluating seed treatment with chemical, bioagent and application of neem cake and their combinations in field during *rabi,* 2020-2021.

MATERIALS AND METHODS

The field experiments were laid out in sandy loamy soils having good drainage facility at Chinthalapalem village, Darsi mandal, Prakasam district during *rabi,* 2020 and 2021 under irrigated dry conditions. Recommended doses of nitrogen, phosphorus and potassium (20-40-40) kg ha^{-1} were applied in the form of urea, single super phosphate and muriate of potash respectively. The groundnut variety 'K-6' with duration of 105-110 days was selected for the study and sown with a spacing of 22.5×10 cm in plots of 5×3 m. All packages of practices recommended for groundnut was followed. Randomised Block Design was adopted with eight treatments *viz.*, T_1- Seed treatment with tebuconazole @1 g kg^{-1} ; T_2- Seed treatment with *T. harzianum* @ 5 g kg^{-1} seed; T_3- Soil application of neem cake @ 1.3 t/ha; T_4- Seed treatment with tebuconazole @ 1 g kg^{-1} + *T. harzianum* @ 5g kg^{-1} seed; T_5- Seed treatment with tebuconazole @ 1g kg^{-1} seed + soil application of neem cake @ 1.3t/ha; T_6- Seed treatment with tebuconazole @ 1 g kg^{-1} + *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3t/ha; T_7- Seed treatment with *T. harzianum* @ 5 g kg^{-1} seed + neem cake @ 1.3 t/ha and T_8 as control plot with three replications.

The observations recorded during field study are percent seed germination, percent disease incidence @ 45 DAS, 60 DAS and 75 DAS, shoot length, root length, number of pods per plant, pod yield and Area Under Disease Progress Curve (AUDPC).

AUDPC was calculated using the formula:

$$\sum_{i=1}^{n}\left[\frac{y_i + y_{i+1}}{2}\right][t_{i+1} - t_i]$$

Where,

n = Total number of observation.

y_i = Disease incidence recorded at the i^{th} observation.

t_i = Time at the i^{th} observation.

The data obtained in the present investigation was analysed statistically using RBD and presented.

RESULTS AND DISCUSSION

During *rabi,* 2020-21

Germination percentage

Among the 8 treatments imposed, T_6 i.e., seed treatment with tebuconazole @ 1 g kg^{-1} seed (ST) + *T. harzianum* @ 5 g kg^{-1} + soil application of neem cake @ 1.3 t/ha recorded significantly higher germination percentage (97.9%) followed by T_4 (seed treatment with tebuconazole 1 g and *T. harzianum* @ 5 g kg^{-1} seed) (96.3%). The least germination percentage (83.7%) has been recorded in T_8 (control) (Table 1).

Per cent disease Incidence

At 45 DAS, highest percent disease incidence (11.49%) among the treatments was recorded with T_3 (soil application of neem cake @ 1.3 t/ha) which was on par with T_2 (seed treatment with *T. harzianum* @ 5 g kg^{-1}) (11.29%). Least PDI (3.50%) was observed in T_6 (seed treatment with tebuconazole @ 1g kg^{-1} seed + *T. harzianum* @ 5 g kg^{-1} + soil application of neem cake @ 1.3 t/ha) followed by T_5 (seed treatment with tebuconazole 1 g kg^{-1} + soil application of neem cake @ 1.3t/ha) which recorded a PDI of 7.62 per cent and 17.99 PDI has been recorded in T_8 (control) (Table 1).

At 60 DAS, T_3 (soil application of neem cake @ 1.3t/ha) recorded the maximum PDI of 22.98 per cent while T_6 (seed treatment with tebuconazole @ 1 g kg^{-1} seed + *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3t/ha) was recorded minimum disease incidence (10.57%) followed by T_7 (seed treatment with *T. harzianum* @ 5g kg^{-1} + soil application of neem cake @ 1.3 t/ha) which recorded 14.02% and 28.93% PDI was recorded in control plot (T_8) (Table 1).

At 75 DAS, T_3 (soil application of neem cake @ 1.3t/ha) recorded the maximum PDI of 24.87 per cent while Least PDI was observed in T_6 i.e., seed treatment with tebuconazole @ 1g kg^{-1} seed + *T. harzianum* @ 5g kg^{-1} seed + soil application of neem cake @ 1.3t/ha (13.38%) and 32.88% PDI was recorded in control plot (T_8) (Table 1).

Area under disease progress curve (AUDPC)

The AUDPC for various treatments was calculated. T_8 (control) recorded highest AUDPC (765.67) while T_6 recorded the least (176.08). Among the individual treatments the descending order of AUDPC is T_3 (537.65) > T_2 (443.19) > T_1 (424.44). Among the combination treatments, AUDPC of T_7 (380.45) > T_4 (363.97) > T_5 (350.17) > T_6 (176.08) (Table 1).

Root length and shoot length

Maximum root and shoot length (14.52 cm and 35.74 cm) was recorded in T_6 (seed treatment with tebuconazole @ 1 g kg^{-1} seed + *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) followed by T_5 (seed treatment with tebuconazole @ 1g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) which recorded a root and shoot length of 12.73 cm and 32.27 cm respectively, while the least root and shoot length (8.66 cm and 20.43 cm) was recorded in T_8 (control) (Table 2).

No of pods per plant and pod yield

Highest number of pods per plant (32.40) was observed in the treatment T_6 (seed treatment with tebuconazole @ 1 g kg^{-1} seed +*T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) followed by T_7 (seed treatment with *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) where the number of pods per plant was 26.00. Least number of pods per plant (13.00) was observed in the control (T_8). Maximum pod yield (3873.33 kg ha^{-1}) with highest benefit cost ratio of 4.54 was recorded with the treatment T_6 (seed treatment with tebuconazole @ 1 g kg^{-1}

seed + *T. harzianum* @ 5g kg^{-1} seed + soil application of neem cake @ 1.3t/ha) followed by T_7 (seed treatment with *T. harzianum* @ 5g kg^{-1} seed + soil application of neem cake @ 1.3t/ha) which recorded a yield of 3150.0 kg ha^{-1} with 3.72 benefit cost ratio, whereas T_8 (control) had the least yield (1240.0 kg ha^{-1}) (Table 2).

During *rabi*, 2021-22

Germination percentage

Among the 8 treatments imposed, T_6 *i.e*., seed treatment with tebuconazole @ 1 g kg^{-1} seed (ST) + *T. harzianum* @ 5 g kg^{-1} + soil application of neem cake @ 1.3 t/ha recorded significantly higher germination percentage (98.5%) followed by T_4 (seed treatment with tebuconazole 1 g and *T. harzianum* @ 5g kg^{-1} seed) (96.9%). The least germination percentage (82.9%) has been recorded in T_8 (control) (Table 3).

Per cent disease Incidence

At 45 DAS, highest percent disease incidence (11.80%) among the treatments was recorded with T_3 (soil application of neem cake @ 1.3 t/ha) which was on par with T_2 (seed treatment with *T. harzianum* @ 5 g kg^{-1}) (11.01%). Least PDI (3.10%) was observed in T_6 (seed treatment with tebuconazole @ 1 g kg^{-1} seed + *T. harzianum* @ 5 g kg^{-1} + soil application of neem cake @ 1.3 t/ha) followed by T_4 (seed treatment with tebuconazole 1g and *T. harzianum* @ 5 g kg^{-1}) which recorded a PDI of 7.61 per cent and 20.07% PDI was recorded in control plot (T_8) (Table 3).

Table 1: Effect of various treatments on germination percentage and percent disease incidence under field conditions during *rabi,* 2020-21.

Treatments	Germination (%)	Per cent disease incidence			AUDPC
		45 DAS	60 DAS	75 DAS	
T_1 (Tebuconazole @ 1 g kg^{-1} ST)	95.4	9.39	17.12	18.53	424.44
	(77.62)	(17.84)	(24.44)	(25.50)	
T_2 (*T. harzianum* @ 5 g kg^{-1}seed ST)	90.8	11.29	18.46	22.23	443.19
	(72.34)	(19.63)	(25.45)	(2813)	
T_3 (Neem cake @ 1.3 t/ha SA)	87.5	11.49	22.98	24.87	537.65
	(69.30)	(19.81)	(28.64)	(29.91)	
T_4 (Tebuconazole @ 1 g kg^{-1} seed ST+	96.3	8.09	15.93	15.39	363.97
T. harzianum @ 5 g kg^{-1} seed ST)	(78.91)	(16.52)	(23.52)	(23.10)	
T_5 (Tebuconazole @ 1 g kg^{-1} seed ST +	95.1	7.62	14.89	20.36	350.17
neem cake @ 1.3 t/ha SA)	(77.21)	(16.02)	(22.70)	(26.82)	
T_6 (Tebuconazole @ 1 g kg^{-1} seed ST +*T. harzianum* @ 5 g kg^{-1} seed ST + neem cake @ 1.3 t/ha SA)	97.9	3.50	10.57	13.38	176.08
	(81.67)	(10.78)	(18.97)	(21.46)	
T_7 (*T. harzianum* @ 5 g kg^{-1} seed (ST)	90.3	8.50	14.02	15.92	380.45
neem cake @ 1.3 t/ha SA)	(71.85)	(16.95)	(21.99)	(23.52)	
T_8 (Control)	83.7	17.99	28.93	32.88	765.67
	(66.19)	(25.10)	(32.54)	(34.99)	
C.D (P = 0.05%)	3.88	2.15	3.45	3.82	
C.V	2.41	12.64	11.05	10.66	

Note: Figures in parenthesis are angular transformed values.

Table 2: Effect of various treatments on root and shoot length, number of pods per plant and pod yield under field conditions during *rabi*, 2020-21.

Treatments	Root length (cm)	Shoot length (cm)	No of pods per plant	Yield (kg ha^{-1})	B:C ratio
T_1 (Tebuconazole @ 1 g kg^{-1} ST)	11.12	29.93	20.33	2796.67	2.50
T_2 (*T. harzianum* @ 5 g kg^{-1}seed ST)	11.41	28.50	18.67	2043.33	2.16
T_3 (Neem cake @ 1.3 t/ha SA)	11.67	26.17	16.67	1783.33	1.66
T_4 (Tebuconazole @ 1 g kg^{-1} seed ST+ *T. harzianum* @ 5g kg^{-1} seed ST)	12.19	31.67	20.33	2450.00	2.80
T_5 (Tebuconazole @ 1 g kg^{-1} seed ST + Neem cake @ 1.3t/ha SA)	12.73	32.27	20.33	2266.67	3.08
T_6 (Tebuconazole @ 1 g kg^{-1} seed ST + *T. harzianum* @ 5g kg^{-1} seed ST + neem cake @ 1.3 t/ha SA)	14.52	35.74	32.40	3873.33	4.54
T_7 (*T. harzianum* @ 5 g kg^{-1} seed (ST) neem cake @ 1.3t/ha SA)	12.54	32.38	26.00	3150.00	3.72
T_8 (Control)	8.66	20.43	13.00	1240.00	1.10
C.D (P = 0.05%)	1.39	1.38	3.02	149.47	
C.V	6.69	2.66	8.54	3.48	

At 60 DAS, T_6 (seed treatment with tebuconazole @ 1 g kg^{-1} seed + *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) recorded minimum disease incidence (9.78%) followed by T_5 (seed treatment with tebuconazole @ 1g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) which recorded 14.32% and 30.44% PDI was recorded in control plot (T_8) (Table 3).

At 75 DAS, T_3 (soil application of neem cake @ 1.3 t/ha) recorded the maximum PDI of 24.87 percent while Least PDI was observed in T_6 *i.e.*, seed treatment with tebuconazole @ 1 g kg^{-1} seed + *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha (13.04%) followed by T_7 (seed treatment with *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) which recorded (14.62%) and 36.15% PDI was recorded in control plot (T_8) (Table 3).

Area under disease progress curve (AUDPC)

The AUDPC for various treatments was calculated. T_8 (control) recorded highest AUDPC (854.28) while T_6 recorded the least (217.05). Among the individual treatments the descending order of AUDPC is T_3 (576.70) > T_2 (480.08) > T_1 (454.15) and among combination treatments, the descending order of AUDPC is T_7 (393.79) > T_5 (388.18) > T_4 (376.00) > T_6 (217.05) (Table 3).

Root length and shoot length

Maximum root and shoot length (14.71 cm, 35.33 cm) was recorded in T_6 (seed treatment with tebuconazole @ 1g kg^{-1} seed + *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) followed by T_5 (seed treatment with tebuconazole @ 1 g kg^{-1} seed + soil application of neem

Table 3: Effect of various treatments on germination percentage and per cent disease incidence under field conditions during *rabi,* 2021-22.

Treatments	Germination	Percent disease incidence			AUDPC
	(%)	45 DAS	60 DAS	75 DAS	
T_1 (tebuconazole @ 1 g kg^{-1} ST)	93.5	8.95	19.05	19.22	454.15
	(75.23)	(17.41)	(25.88)	(26.00)	
T_2 (*T. harzianum* @ 5 g kg^{-1}seed ST)	90.3	11.01	17.12	21.59	480.08
	(71.85)	(19.38)	(24.44)	(27.69)	
T_3 (Neem cake @ 1.3 t/ha SA)	86.5	11.80	23.31	24.87	576.70
	(68.44)	(20.09)	(28.87)	(29.91)	
T_4 (Tebuconazole @ 1 g kg^{-1} seed ST+	96.9	7.61	15.61	15.39	376.00
T. harzianum @ 5 g kg^{-1} seed ST)	(79.86)	(16.01)	(23.27)	(23.10)	
T_5 (Tebuconazole @ 1 g kg^{-1} seed ST +	95.8	7.82	14.32	21.48	388.18
neem cake @ 1.3 t/ha SA)	(78.17)	(16.24)	(22.24)	(27.61)	
T_6 (Tebuconazole @ 1 g kg^{-1} seed ST +*T. harzianum* @ 5g kg^{-1}	98.5	3.10	9.78	13.04	217.05
seed ST + Neem cake @ 1.3 t/ha SA)	(82.97)	(10.14)	(18.22)	(21.17)	
T_7 (*T. harzianum* @ 5 g kg^{-1} seed (ST)	90.1	8.69	15.65	14.62	393.79
neem cake @ 1.3 t/ha SA)	(71.66)	(17.14)	(23.30)	(22.48)	
T_8 (Control)	82.9	20.07	30.44	36.15	854.28
	(65.57)	(26.62)	(33.49)	(36.96)	
C.D (P = 0.05%)	2.95	1.47	2.85	3.15	
C.V	1.84	8.62	8.97	8.65	

Note: Figures in parenthesis are angular transformed values.

Table 4: Effect of various treatments on root and shoot length, number of pods per plant and pod yield under field conditions during *rabi*, 2021-22.

Treatments	Root length (cm)	Shoot length (cm)	No of pods per plant	Yield (kg ha^{-1})	B:C ratio
T_1 (Tebuconazole @ 1 g kg^{-1} ST)	11.01	29.20	19.67	2826.67	2.42
T_2 (*T. harzianum* @ 5 g kg^{-1}seed ST)	11.53	27.83	19.00	2030.00	2.06
T_3 (Neem cake @ 1.3 t/ha SA)	11.81	25.49	17.00	1716.67	1.46
T_4 (Tebuconazole @ 1 g kg^{-1} seed ST + *T. harzianum* @ 5 g kg^{-1} seed ST)	12.48	31.40	19.67	2423.33	2.82
T_5 (Tebuconazole @ 1 g kg^{-1} seed ST + neem cake @ 1.3 t/ha SA)	13.40	32.37	19.67	2260.00	3.20
T_6 (Tebuconazole @ 1 g kg^{-1} seed ST + *T. harzianum* @ 5 g kg^{-1} seed ST + neem cake @ 1.3 t/ha SA)	14.71	35.33	32.73	3966.67	4.60
T_7 (*T. harzianum* @ 5 g kg^{-1} seed (ST) neem cake @ 1.3 t/ha SA)	11.97	32.91	24.67	3076.67	3.68
T_8 (Control)	8.79	20.17	12.33	1236.67	1.98
C.D (P = 0.05%)	1.36	1.82	2.80	168.04	
C.V	6.49	3.54	7.77	3.93	

cake @ 1.3 t/ha) which recorded a root and shoot length of 13.40 cm and 32.37 cm respectively, while the least root and shoot length (8.79 cm and 20.17 cm) was recorded in T_8 (control) (Table 4).

No of pods per plant and pod yield

Highest number of pods per plant (32.73) was observed in the treatment T_6 (seed treatment with tebuconazole @ 1g kg^{-1} seed +*T. harzianum* @ 5g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) followed by T_7 (seed treatment with *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) where the number of pods per plant was 24.67. Least number of pods per plant (12.33) was observed in the control (T_8). Maximum pod yield (3966.67 kg ha^{-1}) with highest benefit cost ratio of 4.60 was recorded with the treatment T_6 (seed treatment with tebuconazole @ 1 g kg^{-1} seed + *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) followed by T_7 (seed treatment with *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) which recorded a yield of 3076.67 kg ha^{-1} with 3.68 benefit cost ratio, whereas T_8 (control) had the least yield (1236.67 kg ha^{-1}) with 1.98 benefit cost ratio (Table 4).

Pooled data (*Rabi*, 2020-21 and 2021-22)

Germination percentage

Treatment T_6 *i.e*., seed treatment with tebuconazole @ 1g kg^{-1} seed (ST) + *T. harzianum* @ 5g kg^{-1} + soil application of neem cake @ 1.3 t/ha recorded significantly higher germination percentage (98.2%) followed by T_4 (seed treatment with tebuconazole 1 g and *T. harzianum* @ 5 g kg^{-1} seed) (96.6%). The least germination percentage (83.33%) has been recorded in T_8 (control) (Table 5).

Per cent disease Incidence

At 45 DAS, highest per cent disease incidence (16.80%) among the treatments was recorded with T_2 (seed treatment with *T. harzianum* @ 5 g kg^{-1}) which was on par with T_3 (soil application of neem cake @ 1.3 t/ha) (17.39%). Least PDI (5.05%) was observed in T_6 (seed treatment with tebuconazole @ 1 g kg^{-1} seed + *T. harzianum* @ 5 g kg^{-1} + soil application of neem cake @ 1.3 t/ha) followed by T_5 (seed treatment with tebuconazole @ 1 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) which recorded a PDI of 11.53 per cent (Table 5).

At 60 DAS, T_6 (seed treatment with tebuconazole @ 1g kg^{-1} seed + *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) recorded minimum disease incidence (15.46%) followed by T_7 (seed treatment with *T. harzianum* @ 5 g kg^{-1}+ soil application of neem cake @ 1.3 t/ha) which recorded 21.85% (Table 5).

At 75 DAS, T_3 (soil application of neem cake @ 1.3 t/ha) recorded the maximum PDI of 37.30 per cent while Least PDI was observed in T_6 *i.e*., seed treatment with tebuconazole @ 1 g kg^{-1} seed + *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha (19.90%). At 75 DAS, maximum PDI was recorded in control plot (T_8) with 50.96% (Table 5).

Area under disease progress curve (AUDPC)

The AUDPC for various treatments was calculated. T_8 (control) recorded highest AUDPC (1213.35) while T_6 recorded the least (343.24). Among the individual treatments the descending order of AUDPC is T_3 (855.53) > T_2 (742.84) > T_1 (665.40) and among combination treatments, the descending order of AUDPC is T_5 (580.88) > T_4 (576.60) > T_7 (573.86) > T_6 (343.24) (Table 5).

Table 5: Pooled data of effect of various treatments on germination percentage and per cent disease incidence under field conditions.

Treatments	Germination	Per cent disease incidence			AUDPC
	(%)	45 DAS	60 DAS	75 DAS	
T_1 (Tebuconazole @ 1 g kg^{-1} ST)	94.43	13.87	26.65	28.14	665.40
	(76.35)	(21.87)	(31.08)	(32.04)	
T_2 (*T. harzianum* @ 5 g kg^{-1}seed ST)	90.57	16.80	27.02	33.03	742.84
	(72.12)	(24.20)	(31.32)	(35.08)	
T_3 (Neem cake @ 1.3 t/ha SA)	87.00	17.39	34.63	37.30	855.53
	(68.87)	(24.65)	(36.05)	(37.64)	
T_4 (Tebuconazole @ 1 g kg^{-1} seed ST+	96.60	11.89	23.74	23.09	576.60
T. harzianum @ 5 g kg^{-1} seed ST)	(79.37)	(20.17)	(29.16)	(28.72)	
T_5 (Tebuconazole @ 1 g kg^{-1} seed ST +	95.47	11.53	22.05	31.10	580.88
neem cake @ 1.3 t/ha SA)	(77.71)	(19.85)	(28.01)	(33.90)	
T_6 (Tebuconazole @ 1 g kg^{-1} seed ST +*T. harzianum* @	98.20	5.05	15.46	19.90	343.24
5 g kg^{-1} seed ST + Neem cake @ 1.3 t/ha SA)	(82.29)	(12.99)	(23.15)	(26.49)	
T_7 (*T. harzianum* @ 5 g kg^{-1} seed (ST)	90.20	12.85	21.85	23.23	573.86
neem cake @ 1.3 t/ha SA)	(71.76)	(20.01)	(27.87)	(28.81)	
T_8 (Control)	83.33	28.03	44.15	50.96	1213.35
	(65.90)	(31.97)	(41.64)	(45.55)	
C.D (P = 0.05%)	1.59	1.41	2.09	2.34	
C.V	0.73	6.07	4.90	4.80	

Note: Figures in parenthesis are angular transformed values.

Table 6: Pooled data of effect of various treatments on root and shoot length, number of pods per plant and pod yield under field conditions.

Treatments	Root length (cm)	Shoot length (cm)	No of pods per plant	Yield (kg ha^{-1})	B:C ratio
T_1 (Tebuconazole @ 1 g kg^{-1} ST)	11.07	29.57	20.00	2811.7	2.46
T_2 (*T. harzianum* @ 5 g kg^{-1}seed ST)	11.47	28.17	18.83	2036.7	2.11
T_3 (Neem cake @ 1.3 t/ha SA)	11.74	25.83	16.83	1750.0	1.56
T_4 (Tebuconazole @ 1 g kg^{-1} seed ST+ *T. harzianum* @ 5 g kg^{-1} seed ST)	12.33	31.53	20.00	2436.7	2.81
T_5 (Tebuconazole @ 1 g kg^{-1} seed ST + neem cake @ 1.3 t/ha SA)	13.07	32.32	20.00	2263.3	3.14
T_6 (Tebuconazole @ 1 g kg^{-1} seed ST + *T. harzianum* @ 5 g kg^{-1} seed ST + neem cake @ 1.3 t/ha SA)	14.62	35.54	32.57	3920.0	4.57
T_7 (*T. harzianum* @ 5 g kg^{-1} seed (ST) neem cake @ 1.3 t/ha SA)	12.25	32.64	25.33	3113.3	3.70
T_8 (Control)	8.72	20.30	12.67	1238.3	1.54
C.D (P = 0.05%)	0.59	0.73	1.05	88.96	
C.V	2.08	1.04	2.14	1.54	

Root length and shoot length

Maximum root and shoot length (14.62 cm, 35.54 cm) was recorded in T_6 (seed treatment with tebuconazole @ 1 g kg^{-1} seed + *T. harzianum* @ 5g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) followed by T_5 (seed treatment with tebuconazole @ 1 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) which recorded a root and shoot length of 13.07 cm and 32.32 cm respectively, while the least root and shoot length (8.72 cm and 20.30 cm) was recorded in T_8 (control) (Table 6).

No of pods per plant and pod yield

Highest number of pods per plant (32.57) was observed in the treatment T_6 (seed treatment with tebuconazole @ 1 g kg^{-1} seed +*T. harzianum* @ 5g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) followed by T_7 (seed treatment with *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) where the number of pods per plant was 25.33. Least number of pods per plant (12.67) was observed in the control (T_8). Maximum pod yield (3920.0 kg ha^{-1}) with highest benefit cost ratio of 4.57 was recorded with the treatment T_6 (seed treatment with tebuconazole @ 1 g kg^{-1} seed + *T. harzianum* @ 5g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) followed by T_7 (seed treatment with *T. harzianum* @ 5 g kg^{-1} seed + soil application of neem cake @ 1.3 t/ha) which recorded a yield of 3113.3 kg ha^{-1} with 3.70 benefit cost ratio, whereas T_8 (control) had the least yield (1238.3 kg ha^{-1}). This may be due to the synergistic effect of chemical control by fungicide along with the use of bio agent and organic amendment. The findings are in agreement with several studies (Sindhu keerthana *et al*., 2022; Karthikeyan *et al*., 2006; Manjunatha *et al*. 2011; Nageswararao *et al*., 2012; Kumar *et al*., 2015; Choudhary and Ashraf, 2019 and Gaikwad *et al*., 2020) which reported enhanced disease control of dry root rot and stem rot in groundnut when organic amendments, fungicides and bio agents were integrated. Also the results of studies conducted by various workers on different crops (Latha *et al*., 2017 in black gram, Thilagavathi *et al*., 2007 in green gram, Rajkumar *et al*., 2019; Manjunatha *et al*., 2011 and Deepa *et al*., 2018 in chickpea, Dhawan *et al*., 2019 in soybean, Adhikary *et al*., 2019 in sesame) for the management of *R. bataticola* have indicated that the integration of chemical, biological and organic measures not only has provided better control of the disease but also enhanced the crop growth and yield when compared to the use of only one of the management measures. (Table 6).

CONCLUSION

Although reduction in disease appearance was recorded in individual treatments with fungicide, bio agents or organic amendments but greater disease control was recorded in treatments combining fungicide and bio agent or bio agent and organic amendment. The PDI was lowest in combination treatments when compared to sole treatments involving only fungicide, bio agent or organic amendment. The same pattern was observed with root length, shoot length, number of pods/plant and pod yield. Overall results indicate that seed treatment with *T. harzianum* @ 5 g kg^{-1}+ soil application of neem cake @ 1.3 t/ha) was superior to all the treatments. It is also recorded highest maximum germination percentage- initial plant population (98.20%), root length (14.62 cm), shoot length (35.54 cm), highest number of pods per plant (32.57), pod yields (3920.0 kg ha^{-1}) and least disease incidence (19.90%) which was a more than two fold decrease when compared to the control (50.96%). All these factors contributed to the almost three fold increase of yield in seed treatment with *T. harzianum* @ 5 g kg^{-1}+ soil application of neem cake @ 1.3 t/ha) when compared to the control with highest benefit cost ratio (4.57). The efficacy of all the three management inputs revealed that treatments involving integration of the inputs performed better in controlling the disease as well as in increasing the yield than imposing individually. Therefore, it can be concluded that integration of cultural, biological and chemical disease management practices not only exerts a synergistic effect on the disease control and also enhances the yield.

Conflict of interest: None.

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