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Integrated Management of Stem Rot of Groundnut Caused by *Sclerotium rolfsii* under *in vitro* Conditions

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ABSTRACT

Background: Groundnut stem rot, caused by *Sclerotium rolfsii*, is notorious for causing significant economic losses in groundnut production worldwide.

Methods: A field trial on the integrated management of stem rot disease in groundnut was conducted at the International Crops Research Institute for Semi-Arid Tropics during the *rabi* seasons of 2021-22 and 2022-23. This involved the use of *in vitro* effective fungicides and biocontrol agents. The experiment was organized in a randomized complete block design (RCBD) featuring ten treatment combinations, including an untreated control, with three replications and a spacing of 30 ×10 cm.

Result: During the field evaluation in the *rabi* seasons of 2021-22 and 2022-23, the bioagents *Trichoderma viride*, *Bacillus cereus* and the fungicide azoxystrobin showed remarkable performance. Among the various treatments, T10, which included *Trichoderma viride* and *Bacillus cereus* as seed treatment (ST) and soil application (SA) along with a reduced rate of azoxystrobin, proved to be the most effective in managing stem rot in groundnut. Treatment T8, consisting of *Trichoderma viride* as ST+SA and a reduced rate of azoxystrobin and treatment T9, featuring *Bacillus cereus* as ST+SA with a reduced rate of azoxystrobin, also demonstrated good disease control under both glasshouse and field conditions. Moreover, these treatments led to significant improvements in growth and yield parameters, with the highest pod yield and benefit-cost ratio recorded. In summary, the bioagents *Trichoderma viride*, *Bacillus cereus* and the fungicide azoxystrobin have shown considerable promise for the effective management of stem rot in groundnut and can be applied in field settings.

Key words: Azoxystrobin, *Bacillus cereus,* Groundnut, *Trichoderma viride*.

INTRODUCTION

Groundnut, scientifically referred to as *Arachis hypogea* L., occupies a significant role as one of the most important oilseed crops globally. China is the top producer of this crop, followed by India, Nigeria and the United States (Groundnut Outlook, Agricultural Market Intelligence Centre, PJTSAU, 2019).

The cultivation of groundnut spans a considerable area of 29.59 million hectares worldwide, leading to a significant total output of 48.75 million tonnes (FAOSTAT, 2019). In India, groundnut is grown over an area of 4.8 million hectares, producing an impressive 9.2 million tonnes (INDIASTAT, 2019). Specifically in the region of Telangana, groundnut farming covers 0.13 million hectares, resulting in a production of 0.30 million tonnes and a notable productivity rate of 2364 kg/ha (Directorate of Economics and Statistics, 2019). They are high in mono-unsaturated fatty acids, primarily oleic acid. It aids in the reduction of LDL (bad cholesterol) and the increase of HDL (good cholesterol) levels within the blood (Vamshi *et al*., 2024).

The groundnut crop is affected by various diseases caused by fungi, bacteria, nematodes and viruses. These diseases adversely influence both the yield of groundnut pods and the quality of the resulting fodder. Among fungal diseases, stem rot, caused by *Sclerotium rolfsii* Sacc, is especially concerning. This disease significantly reduces both the yield and quality of groundnut production and is regarded as one of the most economically important diseases affecting this crop. It is estimated that stem rot results in an annual loss of 10 to 25 per cent in yield (Sturgeon, 1986).

The management of diseases caused by pathogens found in seeds and soil has typically concentrated on seed

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treatment due to the high expense and impracticality of applying chemicals directly to the soil. As a result, alternative methods for disease management have been investigated, with a special focus on biological control. This approach is seen as promising due to its potential effectiveness and environmentally friendly characteristics, making it a valuable complement to synthetic fungicides (Sohaliya *et al*., 2019).

Various studies indicate the widespread use of *Trichoderma* spp., including, *T. virens,T. gamsii, T. atroviride, T. hamatum, T. asperellum, T. harzianum, T. polysporum* and *T. koningii*, as biocontrol agents that effectively combat a range of soil-borne pathogens such as *Phytophthora, Pythium, Aspergillus, Fusarium* and *Rhizoctonia* (Javaid *et al*., 2018; Sharma and Prasad, 2018; Ingale and Patale, 2019). Moreover, the application of organic amendments has been shown to suppress soil-borne pathogens (Bonanomi *et al*., 2018). Numerous studies have also suggested that the antagonistic effectiveness of bacterial or fungal antagonists, such as *P. fluorescens* or *Trichoderma* spp., can be enhanced when combined with organic amendments (Vengadeshkumar *et al*., 2019; Jangir *et al*., 2020). Therefore, an effort was made to identify the most effective biocontrol agent and fungicide for managing *Sclerotium rolfsii*, the causative agent of stem rot in groundnut, by evaluating seed treatment with chemicals, bioagents, neem cake applicationand their combinations in field trials during the *rabi* seasons of 2021-22 and 2022-23.

MATERIALS AND METHODS

Integrated disease management

A field experiment on the integrated management of stem rot disease in groundnut was conducted at the International Crops Research Institute for Semi-Arid Tropics during the *rabi* seasons of 2021-22 and 2022-23, utilizing *in vitro* effective fungicides and biocontrol agents. The experiment was carried out with beds of 1.5×4.0 m^2 size in a randomized complete block design (RCBD) with ten treatment schedules, including an untreated controland three replications with spacing of 30×10 cm. The peanut cultivar K6, known to be susceptible to stem rot, was employed for the study. The treatments for the experiment were as follows:

T1: Un-inoculated control.
T2: Inoculated control.
T3: Effective fungicide at reduced rate.
T4: *Trichoderma viride*as seed treatment (ST).
T5: *Trichoderma viride*as soil application (SA).
T6: *Bacillus cereus*as seed treatment (ST).
T7: *Bacillus cereus*as soil application (SA).
T8: *Trichoderma viride*as ST + SA + reduced rate of azoxystrobin.
T9: *Bacillus cereus*as ST + SA+reduced rate of azoxystrobin.
T10:*Trichoderma viride*and *Bacillus cereus*as ST + SA + reduced rate of azoxystrobin.

Where, ST is seed treatment and SA is soil application.

The bioformulations were mixed with well-decomposed farmyard manure (FYM) and used as a basal application 15 days before planting at a rate of 2.5 kg/ha. The seeds were treated with bioformulations at a rate of 10 g/kg of seeds prior to sowing. T1, T2 and T3 were used to compare the treatments. T3 acted as the control with fungicide, where the seeds were treated with azoxystrobin 23.8 SC (@1 ml/kg seeds) at plantingand azoxystrobin 23.8 SC (@1 ml/l) was applied as a soil drench on the 44th day after sowing. T1 represented the uninoculated control (no pathogen inoculation), while T2 represented the inoculated control (pathogen inoculation). The virulent isolate inoculum was prepared on sorghum grain medium (SGM) On the 45th day after sowing, artificial inoculation was carried out in the field, with 400 g of the virulent isolate inoculum applied per 4-meter row. The inoculum was placed at the collar region of the plants.

A severity scale ranging from 1 to 5 was employed to evaluate the severity of stem rot disease (Shokes *et al*., 1996) and the percentage of disease severity was calculated using the method described by Le *et al*. (2012). In assessing disease severity (DS), approximately 20% of the plant population was consideredand data was recorded at regular intervals. Additional observations such as disease incidence (DI) and mortality (M) were also noted. All observations were made 15 days post-inoculation and continued at 15-day intervals until harvest. During harvesting, plants were uprooted and examined for stem discoloration, pod lesionsand pod rot. Subsequently, various yield-related attributes were recorded, including plant height (in centimeters), germination percentage, number of pods per plant, pod yield per plot, 100-kernel weight, shelling percentage, oil content percentage, protein content percentage and the benefit-to-cost (BC) ratio.

RESULTS AND DISCUSSION

Integrated disease management of stem rot of groundnut

The study was conducted to assess the effectiveness of talc formulations containing the bioagents *Trichoderma viride* and *Bacillus cereus*, both separately and in combination, for managing stem rot disease in groundnut. Bioagent *Trichoderma viride* and *Bacillus cereus* was found compatible with azoxystrobin. Hence, their efficacy was further evaluated under field conditions. The experiments took place at ICRISAT, Patancheru during the *rabi* seasons of 2021-22 and 2022-23.

The efficacy of these treatments was evaluated by measuring their effects on the severity, incidence of stem rot disease and mortality of plants, which was caused by a highly virulent strain of *Sclerotium rolfsii* (SrPWp) in groundnut plants grown under field conditions. Data analysis presented in tables indicated a gradual increase in disease severity, incidence and mortality of groundnut plants over time following inoculation.

Disease severity

The effectiveness of treatments on the severity of stem rot disease in groundnut caused by *S. rolfsii* was examined and the results indicated that during the *rabi* season of 2021-22, treatment T10, which combined *Trichoderma viride* and *Bacillus cereus* as seed treatment (ST) + soil application (SA) + a reduced rate of azoxystrobin, exhibited the lowest disease severity at 13.23%. This was followed by treatment T3, which used azoxystrobin at a reduced rate, resulting in a disease severity of 14.74% and treatment T8, which included *Trichoderma viride* as ST + SA + reduced rate of azoxystrobin, showing a disease severity of 17.02% at 15 days post-inoculation (dpi). At 30 dpi, treatment T10 again displayed the lowest disease severity at 28.47%, followed by treatment T8 with 33.54%. This pattern was consistently observed at 45, 60 and 75 dpi. Overall, treatment T10 recorded a significantly lower mean disease severity of 35.51%, while treatments T8 (40.16%) and T9 (43.36%) were comparable to each other.

Similarly, a comparable trend was noted during the *rabi* season of 2022-23, where a significantly lower average disease severity was observed with treatment T10 (comprising *Trichoderma viride* and *Bacillus cereus* as seed treatment (ST) + soil application (SA) + reduced rate of azoxystrobin) at 11.21. This was followed by treatment T3 (azoxystrobin at a reduced rate) at 12.68 and treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) at 15.26 at 15 days post-inoculation (dpi). Treatment T10 (26.76%) exhibited the least disease severity at 30 dpi, followed by treatment T8 at 28.98%. A similar pattern was observed at 45, 60 and 75 dpi. Overall, treatment T10 (comprising *Trichoderma viride* and *Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) recorded a significantly lower mean disease severity of 32.77%. This was followed by treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) at 36.53 and treatment T9 (*Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) at 39.51, which were found to be statistically comparable to each other.

Interestingly similar trend was noted in pooled data, where the treatment T10 was found most effective followed by treatment T8 and treatment T9 (Fig 1).

Disease incidence

A similar trend was noted in the effectiveness of treatments on the incidence of stem rot disease in groundnut caused by *S. rolfsii* under field conditions. During the *rabi* season of 2021-22, treatment T10 (*Trichoderma viride* and *Bacillus cereus* as seed treatment (ST) + soil amendment (SA) + reduced rate of azoxystrobin) exhibited a significantly lower disease incidence of 21.45 per cent. Additionally, treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) (25.45%) was identified as the next most effective treatment and it was comparable to treatment T9 (*Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) (27.56%) at 15 days post-inoculation (dpi). A similar pattern was observed at 30, 45, 60 and 75 dpi. Overall, treatment T10 (*Trichoderma viride* and *Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) demonstrated a significantly lower average disease incidence of 32.55 per cent, followed by treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) with a disease incidence of 37.86 percent, which was comparable to treatment T9 (*Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) at 39.47 per cent.

Similarly, a comparable trend was noted during the *rabi* season of 2022-23, where a significantly lower average disease incidence of 30.26 per cent was recorded with treatment T10 (*Trichoderma viride* and *Bacillus cereus* as seed treatment (ST) + soil amendment (SA) + reduced rate of azoxystrobin). This was followed by treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) with a disease incidence of 38.37 per cent and treatment T9 (*Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) with a disease incidence of 39.19 per cent. Further, similar trend was noted in pooled data, where treatment T10 was found most effective. Additionally, treatment T8 was found to be next best treatment which was at par with treatment T9 (Fig 2).

Mortality

All the treatments were effective in lowering the mortality of groundnut plants, although there were variations in the percentage of mortality among the treatments. It was noted that as the crop aged, there was a gradual increase in mortality from 30 days after inoculation to 75 days after inoculation, although the percentage of mortality was lower from 60 to 75 days after inoculation compared to the inoculated control across all treatments. Treatment T10 (*Trichoderma viride* and *Bacillus cereus* as seed treatment (ST) + soil amendment (SA) + reduced rate of azoxystrobin) was particularly effective in reducing mortality, followed by T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) when compared to the inoculated control. Both of these treatments proved to be more effective than the seed treatment and foliar application of the fungicide azoxystrobin in decreasing mortality.

The treatments exhibited significant differences in managing the mortality of groundnut plants caused by *S. rolfsii* under field conditions. During the *rabi* season of 2021-22, no mortality was observed at 15 days post-inoculation (dpi) across all treatments. At 30 dpi, treatment T10 (*Trichoderma viride* and *Bacillus cereus* as seed treatment (ST) + soil amendment (SA) + reduced rate of azoxystrobin) recorded the lowest mortality at 6.46%. Treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) (8.24%) was identified as the next most effective treatment, which was comparable to treatment T9 (*Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) (10.42%) and this trend continued at 45, 60 and 75 dpi. Overall, treatment T10 (*Trichoderma viride* and *Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) recorded a significantly lower mean mortality of 10.02%. Treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) (13.87%) was the next best treatment and was comparable to T9 (*Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) (16.19%).

Interestingly, a similar trend was observed during the *rabi* season of 2022-23 and in pooled data, where treatment T10 (*Trichoderma viride* and *Bacillus cereus* as seed treatment (ST) + soil amendment (SA) + reduced rate of azoxystrobin) was found to be the most effective in managing mortality caused by *S. rolfsii* under field conditions. Furthermore, treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) was identified as the next best treatment, which was comparable to treatment T9 (*Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) (Fig 3).

Growth promoting traits

The treatments significantly enhanced various growth-promoting traits in groundnut under field conditions. During the *rabi* season of 2021-22, treatment T10 (*Trichoderma viride* and *Bacillus cereus* as seed treatment (ST) + soil amendment (SA) + reduced rate of azoxystrobin) achieved a notably higher germination percentage of 78.42%, followed by treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) with 75.34%, which was

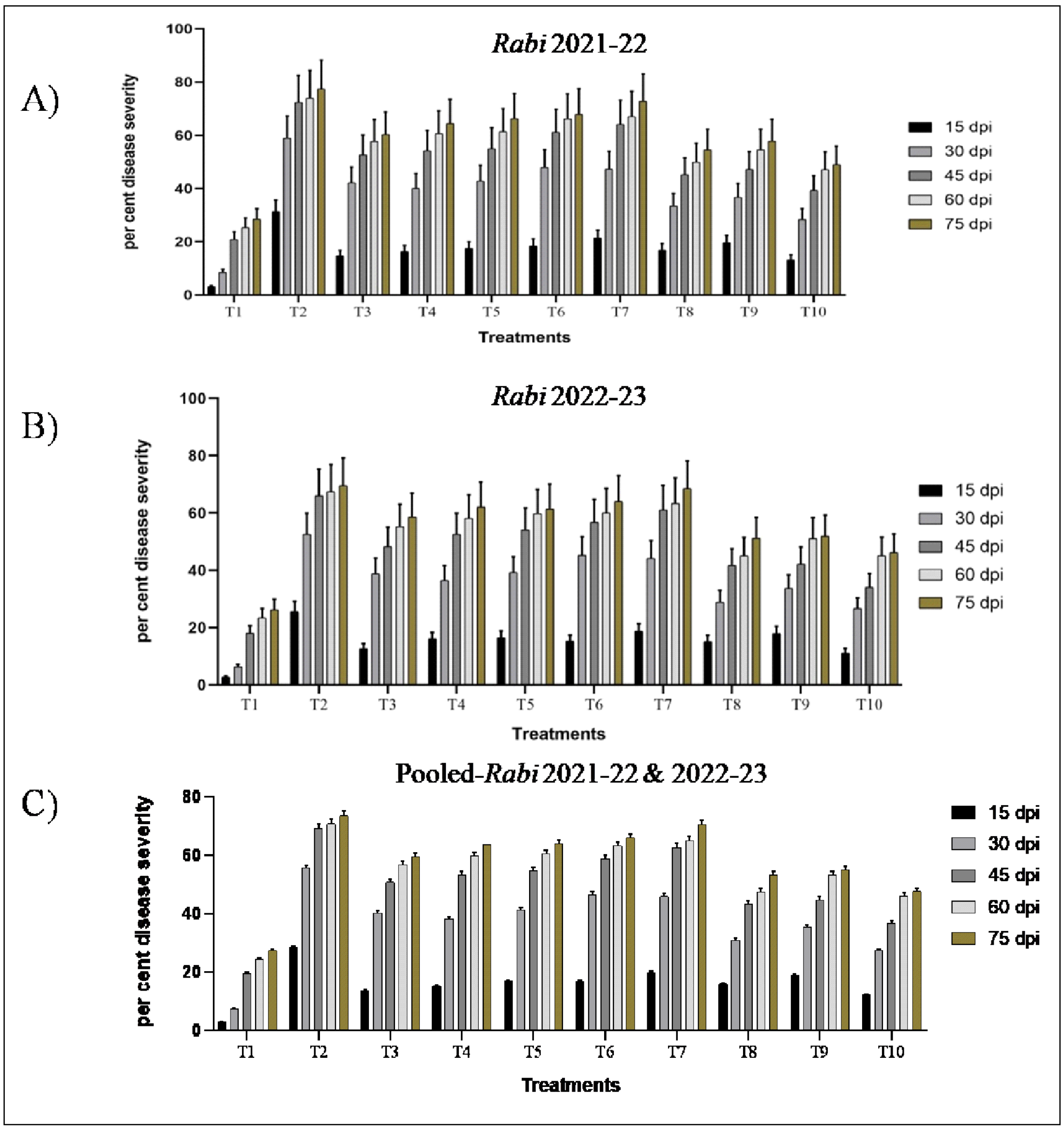

Fig 1: Impact of seed treatment and soil application of *Trichoderma viride*, *Bacillus cereus* and fungicide along with their combinations on stem rot severity in groundnut under field conditions.

comparable to treatment T9 (*Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) at 74.92%. Similar results were observed in terms of plant height, where treatment T10 (*Trichoderma viride* and *Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) was significantly superior at 48.23 cm. Treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) was the next best with 45.76 cm, comparable to treatment T9 (*Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) at 44.80 cm. Moreover, the various treatments did not show significant differences in oil and protein content, which ranged from 41.75 to 47.78% and 21.79 to 24.96%, respectively, indicating that these treatments had no detrimental effect on the oil and protein content of groundnut under field conditions. A similar trend was noted during the *rabi* season of 2022-23 and in pooled data. However, the oil and protein contents were not significantly different in any of the treatments compared to the inoculated control (Table 1).

Yield and yield related traits

All treatments had a beneficial impact on yield and yield-related traits under field conditions. During the *rabi* season of 2021-22, treatment T10 (*Trichoderma viride* and *Bacillus cereus* as seed treatment (ST) + soil amendment (SA) + reduced rate of azoxystrobin) recorded the highest number of pods per plant at 29.74, followed by treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) at 26.63 and treatment T9 (*Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) at 27.16, which were comparable to each other. Regarding 100-kernel weight, treatment T10 (*Trichoderma viride* and *Bacillus cereus* as ST + SA + reduced rate of azoxystrobin)

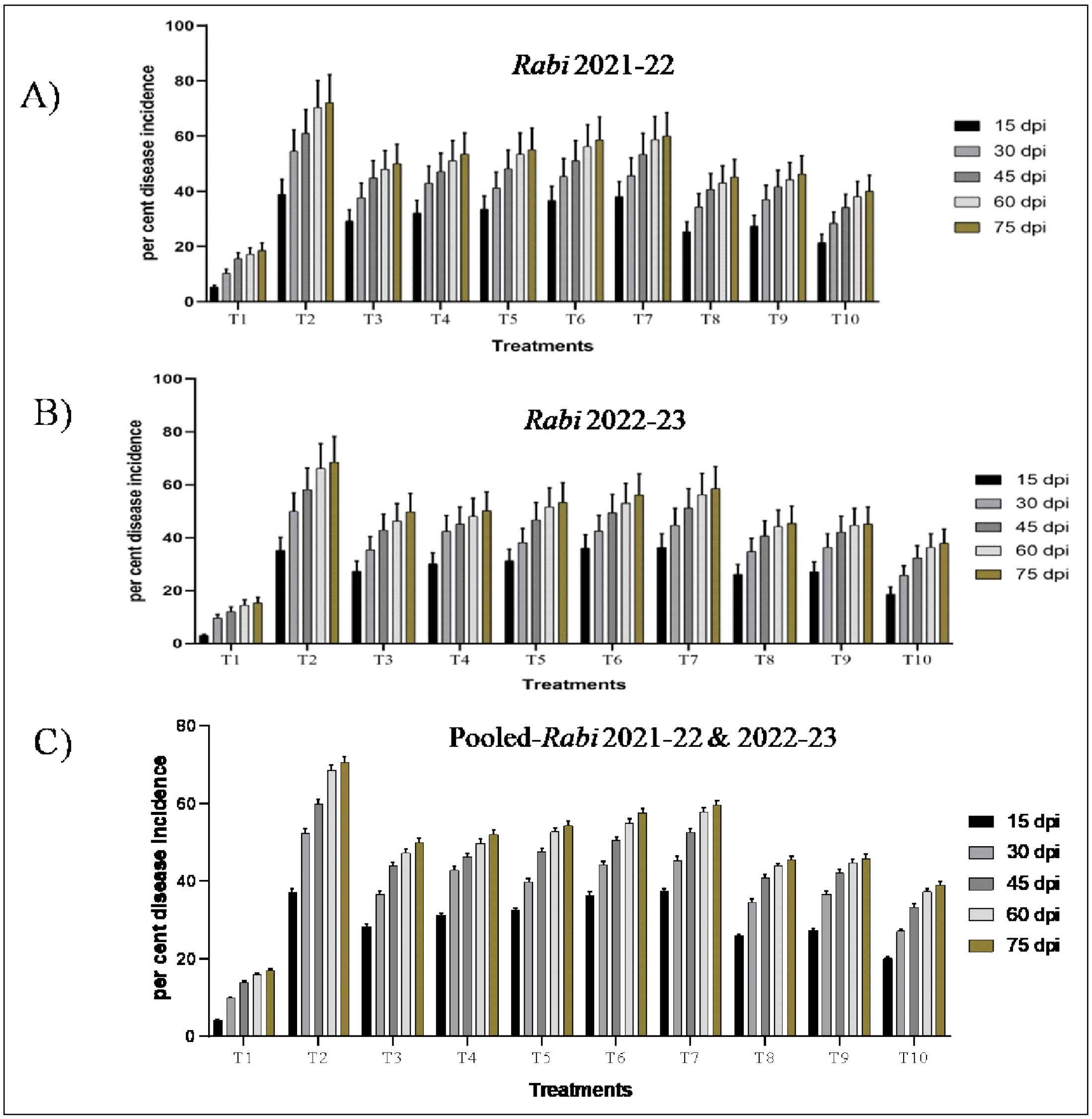

Fig 2: Impact of seed treatment and soil application of *Trichoderma viride*, *Bacillus cereus* and fungicide along with their combinations on stem rot incidence in groundnut under field conditions.

performed significantly better at 40.75 g, followed by treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) at 38.42 g. Similarly, the highest shelling percentage was noted in treatment T10 (*Trichoderma viride* and *Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) at 74.25%, followed by treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) at 70.83%. Similar results were observed for pod yield, with treatment T10 (*Trichoderma viride* and *Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) being significantly superior at 2430.42 kg/ha, followed by treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) at 2245.63 kg/ha. Notably, treatment T10 (*Trichoderma viride* and *Bacillus cereus* as ST + SA + reduced rate of azoxystrobin) recorded the highest benefit-to-cost (BC) ratio of 2.86, followed by treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin) at 2.74. A similar trend was observed during the *rabi* season of 2022-23 and in pooled data (Table 2).

Therefore, based on the results, treatment T10 (*Trichoderma viride* and *Bacillus cereus* as seed treatment (ST) + soil amendment (SA) + reduced rate of azoxystrobin) was found to be significantly the most effective in managing stem rot disease in groundnut under field conditions. This treatment was comparable to treatment T8 (*Trichoderma viride* as ST + SA + reduced rate of azoxystrobin), followed by treatment T9 (*Bacillus cereus* as ST + SA + reduced rate of azoxystrobin).

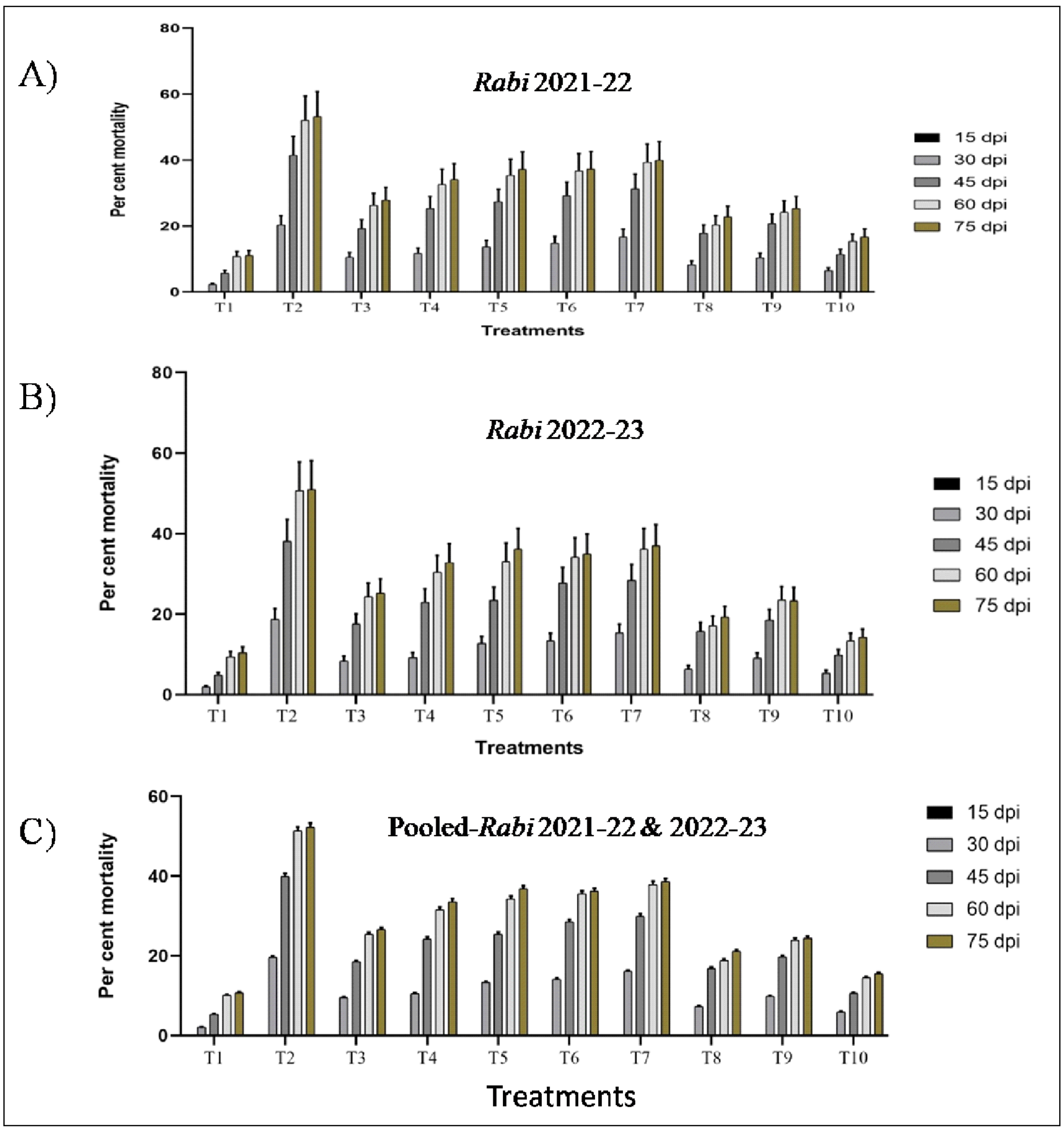

Fig 3: Impact of seed treatment and soil application of *Trichoderma viride*, *Bacillus cereus* and fungicide along with their combinations on stem rot mortality in groundnut under field conditions.

Table 1: Impact of seed treatment and soil application of *Trichoderma viride*, *Bacillus cereus* and fungicide along with their combinations on growth characteristics of groundnut under field conditions.

Treatments	Location I				Location II				Pooled			
	Germ (%)	Plant height (cm)	Oil content (%)	Protein content (%)	Germ (%)	Plant height (cm)	Oil content (%)	Protein content (%)	Germ (%)	Plant height (cm)	Oil content (%)	Protein content (%)
T1	71.42	40.99	42.49	22.48	61.25	36.47	40.28	20.28	66.335	38.73	41.385	21.38
T2	70.42	39.23	41.75	21.79	60.00	34.26	39.49	18.34	65.21	36.745	40.62	20.065
T3	74.33	44.03	43.15	22.75	62.75	38.92	40.37	20.76	68.54	41.475	41.76	21.755
T4	71.96	41.80	44.36	23.73	59.30	39.29	41.29	20.43	65.63	40.545	42.825	22.08
T5	71.84	41.13	44.79	23.34	60.25	40.72	41.16	21.46	66.045	40.925	42.975	22.4
T6	73.23	43.96	45.84	24.46	59.30	41.38	42.48	22.37	66.265	42.67	44.16	23.415
T7	72.20	42.68	45.43	24.75	61.92	38.85	43.28	21.26	67.06	40.765	44.355	23.005
T8	75.34	45.76	46.99	23.76	65.23	42.42	43.74	22.49	70.285	44.09	45.365	23.125
T9	74.92	44.80	46.22	22.78	63.98	40.38	43.41	22.90	69.45	42.59	44.815	22.84
T10	78.42	48.23	47.78	24.96	68.12	45.21	44.46	23.48	73.27	46.72	46.12	24.22
Mean	73.408	43.26	44.88	23.48	62.21	39.79	41.99	21.37	67.80	41.52	43.438	22.42
CD (0.05)	5.40	6.32	(NS)	(NS)	7.40	6.61	(NS)	(NS)	4.20	4.25	(NS)	(NS)
S.Em.±	1.32	1.55	2.45	1.63	1.81	1.62	2.48	1.03	1.47	1.49	2.21	1.27
CV (%)	7.13	8.21	9.48	12.07	8.06	7.07	10.24	8.39	7.06	8.24	10.24	8.39

Table 2: Impact of seed treatment and soil application of *Trichoderma viride*, *Bacillus cereus* and fungicidealong with their combinations on yield characteristics of groundnut under field conditions.

Treatments	Location I					Location II					Pooled				
	Pods/ plant	100 kernel weight (g)	Shelling (%)	Pod yield (kg/ha)	B : C ratio	Pods/ plant	100 kernel weight (g)	Shelling (%)	Pod yield (kg/ha)	B : C ratio	Pods/ plant	100 kernel weight (g)	Shelling (%)	Pod yield (kg/ha)	B : C ratio
T1	22.62	34.84	64.30	1729.48	1.94	25.34	36.61	66.68	1942.86	2.04	23.98	35.72	65.49	1836.17	1.99
T2	20.43	32.96	59.36	1534.82	1.86	23.79	35.38	62.31	1681.34	1.98	22.11	34.17	60.83	1608.08	1.92
T3	25.82	36.83	68.96	1988.26	2.15	28.80	40.49	69.94	2296.83	2.41	27.31	38.66	69.45	2142.54	2.28
T4	23.73	35.85	65.18	1834.25	2.02	26.78	38.74	67.20	2084.24	2.24	25.25	37.29	66.19	1959.24	2.13
T5	22.49	34.12	64.58	1708.44	1.91	26.34	38.20	66.95	1932.62	2.06	24.415	36.16	65.76	1820.53	1.98
T6	25.30	36.46	67.89	2074.23	2.48	28.20	40.39	69.30	2238.30	2.59	26.75	38.42	68.59	2156.26	2.53
T7	24.58	36.20	65.13	1912.48	2.05	27.49	39.24	68.12	2127.64	2.34	26.03	37.72	66.62	2020.06	2.19
T8	26.63	38.42	70. 83	2245.63	2.74	29.78	42.39	73. 46	2482.87	2.85	28.20	40.40	72.14	2364.25	2.79
T9	27.16	37.65	68.14	2123.94	2.58	28.94	40.23	71.39	2426.32	2.76	28.05	38.94	69.76	2275.13	2.67
T10	29.74	40.75	74.25	2430.42	2.86	31.74	45.03	76.62	2684.30	3.02	30.74	42.89	75.43	2557.36	2.94
Mean	24.85	36.40	66.42	1958.19	2.25	27.72	39.67	68.72	2189.73	2.42	26.28	38.03	68.026	2073.96	2.34
CD (0.05)	6.00	4.90	9.63	558.31	-	5.93	7.30	8.76	514.58	-	3.76	3.96	5.80	119.12	-
S.Em.±	1.47	1.20	2.36	137.17	-	1.45	1.79	2.15	126.43	-	1.32	1.39	2.03	339.31	-
CV (%)	10.28	7.73	7.12	12.13	-	9.11	7.79	7.39	10.00	-	9.06	7.80	7.14	12.13	-

The results align with the findings of Dubey *et al*. (2015), who showed that the combined application of *P. fluorescens*, *Mesorhizobium ciceri* and *T. harzianum* along with the fungicide vitavax (carboxin and thiram) in chickpea led to the highest seed germination, grain yieldand the lowest incidence of wilt caused by *F. oxysporum* in both pot and field experiments.

Babu and Deepika, (2023) reported that 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.

Gireesha *et al*. (2024) reported that the seed treatment fungicides mancozeb 50% + carbendazim 25% WP and carboxin 37.5% + thiram 37.5% DS were the most effective against *M. phaseolina*. Similarly, among the bioagents tested, *T. harzianum* proved to be the most effective, followed by *T. viride* and *P. fluorescens*. A two-year evaluation of nine integrated treatment modules for *rabi* seasons showed that seed treatment with carboxin 37.5% + thiram 37.5% WS resulted in the lowest disease incidence and the highest grain yield, 100-seed weightand benefit-cost (BC) ratio.

Furthermore, Jambhulkar *et al*. (2018) reported that the combination of *T. harzianum*, *P. fluorescens*and carbendazim was more effective against *Magnaporthe oryzae* compared to their individual applications in field experiments with rice. Additionally, the effectiveness of various methods for applying bioagents was documented by Nandakumar *et al*. (2001); Vidhyasekaran *et al*. (1997); Vidhyasekaran and Muthamilan (1999) and Meena *et al*. (2000); Saravanakumar (2006) in the control of various soil-borne fungal pathogens.

CONCLUSION

During field and greenhouse studies, the effectiveness of talc formulations containing the bioagents *Trichoderma viride* and *Bacillus cereus*, both individually and in combination, for managing stem rot disease was assessed during the *rabi* seasons of 2021-22 and 2022-23. The bioagents *Trichoderma viride*, *Bacillus cereus* and the fungicide azoxystrobin showed remarkable performance. Treatment T10 (*Trichoderma viride* and *Bacillus cereus* as seed treatment, soil amendmentand reduced rate of azoxystrobin) was identified as the most effective in controlling stem rot in groundnut, followed by treatment T8 (*Trichoderma viride* as seed treatment, soil amendment and reduced rate of azoxystrobin) and treatment T9 (*Bacillus cereus* as seed treatment, soil amendment and reduced rate of azoxystrobin) under both greenhouse and field conditions. Treatment T10 (*Trichoderma viride* and *Bacillus cereus* as seed treatment, soil amendment and reduced rate of azoxystrobin) demonstrated a significant increase in growth and yield-related parameters in groundnut under field conditions.

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Conflict of interest

The authors declare no conflicts of interest.

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