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Management of Seed and Stem Rot (*Sclerotium rolfsii*) in Groundnut using Fungicides and Bioagents: Its Economics and Multivariate Analysis

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ABSTRACT

Background: Seed and stem rot caused by *Sclerotium rolfsii* is a major constraint limiting groundnut productivity under field conditions. **Methods:** A field experiment was conducted to evaluate chemical, biological and integrated treatments for the management of seed rot and stem rot and their impact on yield and economic returns for two-season.

Result: Significant variation among treatments was observed, with minimum stem rot incidence recorded in T_7 (Seed treatment with (Thiophanate Methyl 45% + Pyraclostrobin 5%) FS @ 2.0 ml/kg seeds) (3.43%) followed by T_8 (Seed treatment with (Imidacloprid 18.5% + Hexaconazole 1.5% FS) 50 FS @ 1.0 ml/kg seeds) (4.27%), whereas the control showed the highest incidence (21.38%). Correspondingly, maximum pod yield was obtained in T_7 (21.69 q ha^{-1}) followed by T_8 (20.52 q ha^{-1}), while the lowest yield was recorded in the control (11.62 q ha^{-1}). Correlation and regression analyses revealed a strong negative relationship between disease incidence and yield and the disease-yield loss model ($R^2 \approx 0.92$) indicated substantial yield reduction with increasing disease severity. Multiple regression ($R^2 = 0.993$) and path analysis identified haulm yield as the major determinant of pod yield, while disease influenced yield indirectly through its effect on plant growth. Multivariate analyses, including PCA and cluster analysis, clearly differentiated treatments and the combined performance index ranked T_7 as the best treatment followed by T_8 and T_1. Overall, the study demonstrates that effective suppression of stem rot significantly improves germination, yield and profitability in groundnut and integrated management approaches combining chemical and biological strategies (*Trichoderma* sp. seed treatment @10 g/kg seeds and enriched FYM with *Trichoderma* @ 2.5 kg/250 kg FYM) provide a sustainable and efficient solution under field conditions.

Key words: Disease management, Groundnut, *Sclerotium rolfsii*, Stem rot, Yield loss.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is one of the most important oilseed crops cultivated in tropical and subtropical regions, contributing significantly to food security, edible oil production and rural livelihoods. It contains about 45-50% oil and 25-30% protein, making it a nutritionally rich crop with high economic value. Globally, groundnut production is affected by several biotic and abiotic stresses, among which diseases caused by soil-borne pathogens are particularly destructive (Deepika *et al.*, 2025).

Among these, stem rot and seed rot caused by *Sclerotium rolfsii* Sacc. (syn. *Athelia rolfsii*) represent major constraints in groundnut cultivation across diverse agro-climatic regions. The pathogen is widely distributed in tropical and subtropical regions and is capable of infecting more than 500 plant species, highlighting its ecological adaptability and survival potential (Punja, 1985; Deepika *et al.*, 2025). Stem rot is considered one of the most economically important diseases of groundnut, causing severe yield and quality losses worldwide (Mehan *et al.*, 1994; Vamshi *et al.*, 2025). Yield losses due to this disease generally range from 15-70%, but under favourable environmental conditions, losses may exceed 80% (Akgul *et al.,* 2011).

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The disease manifests at multiple growth stages, beginning with seed rot and seedling blight and progressing to stem rot and pod rot in later stages. Characteristic symptoms include yellowing, wilting, necrosis and the formation of white mycelial mats with mustard-like sclerotia at the collar region of infected plants (Ayyandurai *et al.,* 2022; Deepika *et al.*, 2025). The pathogen survives in soil as sclerotia for extended periods, enabling it to persist across seasons and making management particularly challenging (Bosamia *et al.*, 2020). Environmental factors such as high temperature (25-30°C), moderate soil moisture and sandy soils further favor disease development and epidemic outbreaks (Deepika *et al.,* 2025).

Management of *S. rolfsii* is difficult due to its soil-borne nature, wide host range and long-term survival structures. Conventional management strategies relying solely on fungicides have shown effectiveness but are often associated with environmental hazards, development of resistant pathogen populations and disruption of soil microbial balance (Bonanomi *et al.,* 2018; Meena *et al.*, 2024). Biological control approaches using antagonistic microorganisms such as *Trichoderma* spp., *Pseudomonas fluorescens* and *Bacillus subtilis* have shown promising results in suppressing the pathogen and improving plant growth (Ganesan, 1987; Jacob *et al.*, 2018; Meena *et al.*, 2024; Vamshi *et al.,* 2025).

Recent studies emphasize the importance of integrated disease management (IDM) strategies combining chemical, biological and organic approaches for effective control of stem rot. Integration of bioagents with organic amendments such as farmyard manure or vermicompost enhances microbial activity, improves soil health and increases disease suppression efficiency (Nathawat *et al.,* 2025; Vamshi *et al.*, 2025; Hotkar *et al.,* 2026). Such approaches not only reduce disease incidence but also improve yield and sustainability of groundnut production systems (Vamshi *et al.,* 2025).

Despite the availability of various management options, variability in pathogen populations, environmental conditions and cropping systems necessitates location-specific evaluation of integrated management strategies. Moreover, limited information is available on the combined management of seed rot and stem rot under field conditions across multiple seasons. Therefore, the present investigation was undertaken to evaluate the effectiveness of different chemical and biological treatments, individually and in combination, for the management of seed rot and stem rot diseases of groundnut under field conditions.

MATERIALS AND METHODS

Experimental site and design

The field experiment was conducted during *Kharif* 2024 and 2025 at Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad, Karnataka, India under natural field conditions (sick plot). The experimental site was characterized by typical groundnut-growing agro-climatic conditions, conducive for the development of soil-borne diseases, particularly stem rot caused by *Sclerotium rolfsii*. The experiment was laid out in a randomized block design (RBD) with nine treatments and three replications. Groundnut was grown following recommended agronomic practices, except for plant protection measures specific to the treatments under study. Standard spacing and crop management practices were maintained uniformly across all treatments.

Treatments

The treatments consisted of chemical fungicides, bioagents and their combinations, including enriched organic amendments. The details of treatments are presented in Table 1.

Preparation and application of bioagents

Bioagents (*Trichoderma harzianum* Rifai and *Pseudomonas fluorescens*-collected from Institute of organic farming, UAS, Dharwad, Karnataka) were applied as seed treatment by coating seeds uniformly at the specified dose prior to sowing. For enriched FYM treatments, the respective bioagents were mixed thoroughly with well-decomposed farmyard manure and incubated under shade for adequate multiplication before application to soil at sowing.

Table 1: Details of treatments evaluated for the management of stem rot (*Sclerotium rolfsii*) in groundnut.

Sl. no	Treatment details
T_1	Seed treatment with (Carboxin 37.5% + Thiram 37.5%) 75 WP @ 3.0 g/kg of seeds + Soil drenching with Tebuconazole 25.9 EC @ 2.0 ml/litre at 60 DAS
T_2	Seed treatment with *Trichoderma harzianum* @ 10.0 g/kg seeds
T_3	Seed treatment with *P. fluorescens* @ 10.0 g/kg seeds
T_4	Seed treatment with *Trichoderma harzianum* @ 10.0 g/kg seeds + FYM enriched with *Trichoderma harzianum* @ 2.5 kg in 250 kg FYM
T_5	Seed treatment with *P. fluorescens* @ 10.0 g/kg seeds + FYM enriched with *P. fluorescens* @ 2.5 kg in 250 kg FYM
T_6	Seed treatment with (Carboxin 37.5% + Thiram 37.5%) 75 WP @ 3.0 g/kg of seeds
T_7	Seed treatment with (Thiophanate Methyl 45% + Pyraclostrobin 5%) FS @ 2.0 ml/kg seeds
T_8	Seed treatment with (Imidacloprid 18.5% + Hexaconazole 1.5% FS) 50 FS @ 1.0 ml/kg seeds
T_9	Inoculated control

Germination percentage

Seed germination was recorded by counting the number of emerged seedlings in each treatment and expressed as percentage.

Disease assessment

Observations on stem rot incidence (%) were recorded at appropriate crop growth stages by counting the total number of plants and the number of infected plants in each plot. Disease incidence was calculated using the following formula:

Disease incidence (%) =

$$\frac{\text{Number of infected plants}}{\text{Total number of plants}} \times 100$$

Yield parameters

At harvest, pod yield and haulm yield were recorded from each plot and converted into kg/ha. The pooled data of two seasons were used for analysis and interpretation.

Economic analysis

Economic parameters such as cost of cultivation, gross returns, net returns and benefit-cost (B:C) ratio were calculated based on prevailing market prices of inputs and produce. Cost and return analysis were conducted following the procedures outlined by Kushwah *et al.* (2017) and Bhupender *et al.* (2020). The B:C ratio was computed to determine the economic feasibility of different treatments.

Benifit cost ratio =

$$\frac{\text{Gross return per hectare}}{\text{Total cost of production per hectare}}$$

Statistical analysis

The experimental data obtained from two seasons were subjected to statistical analysis using analysis of variance (ANOVA) appropriate for a randomized block design as described by Panse and Sukhatme (1985). Percentage data on disease incidence were subjected to angular transformation prior to analysis. Treatment means were compared using the critical difference (CD) at 5% level of significance. In addition, correlation, regression and path coefficient analyses were performed to assess relationships among variables and to quantify direct and indirect effects on yield. Multivariate analyses, including principal component analysis (PCA) and cluster analysis, were carried out to understand treatment grouping and trait interactions. All analyses were performed using standard statistical procedures.

RESULTS AND DISCUSSION

Effect of treatments on germination

Significant differences among treatments were observed in seed germination across two seasons (Table 2). The highest germination was recorded in T_7- (Seed treatment with (Thiophanate Methyl 45% + Pyraclostrobin 5%) FS @ 2.0 ml/kg seeds) (94.50%), followed by T_8- (Seed treatment with (Imidacloprid 18.5% + Hexaconazole 1.5% FS) 50 FS @ 1.0 ml/kg seeds) (92.35%) and T_1- (Seed treatment with (Carboxin 37.5% + Thiram 37.5%) 75WP @ 3.0 g/kg of seeds + Soil drenching with Tebuconazole 25.9EC @ 2.0 ml/litre at 60 DAS) (90.51%), indicating the superiority of fungicidal treatments in improving seed health. Bioagent treatments also enhanced germination compared to control, with T_4- (Seed treatment with *Trichoderma harzianum* @ 10.0 g/kg seeds: POP check) (88.89%) and T_5- (Seed treatment with *Trichoderma harzianum* @ 10.0 g/kg seeds + FYM enriched with *Trichoderma harzianum* @ 2.5 kg in 250 kg FYM) (88.35%) showing appreciable improvement. The lowest germination was recorded in the inoculated control (80.33%), confirming the detrimental effect of pathogen inoculation on seedling establishment. Improved germination and reduced stem rot incidence under fungicidal treatments indicate effective suppression of seed- and soil-borne inoculum during early crop stages, which is critical for limiting *Sclerotium rolfsii* infection and ensuring better crop establishment (Mehan *et al.*, 1994; Akgul *et al.*, 2011; Meena *et al.*, 2024).

Effect on stem rot incidence

All treatments significantly reduced stem rot incidence compared to the control (Table 2 and Fig 1a). The lowest pooled disease incidence was recorded in T_7- Seed treatment with (Thiophanate Methyl 45% + Pyraclostrobin 5%) FS @ 2.0 ml/kg seeds (3.43%), followed by T_8- Seed treatment with (Imidacloprid 18.5% + Hexaconazole 1.5% FS) 50 FS @ 1.0 ml/kg seeds (4.27%) and T_1- Seed treatment with (Carboxin 37.5% + Thiram 37.5%) 75WP @ 3.0 g/kg of seeds + Soil drenching with Tebuconazole 25.9EC @ 2.0 ml/litre at 60DAS (5.60%), demonstrating the higher efficacy of fungicidal treatments. Among bioagents, T_4- Seed treatment with *Trichoderma harzianum* @ 10.0 g/kg seeds + FYM enriched with *Trichoderma harzianum* @ 2.5 kg in 250 kg FYM (9.22%) and T_5 (Seed treatment with *P. fluorescens* @ 10.0 g/kg seeds + FYM enriched with *P. fluorescens* @ 2.5 kg in 250 kg FYM) (10.18%) were more effective than seed treatment alone, indicating the added benefit of FYM enrichment. The highest disease incidence was recorded in the control (21.38%), clearly indicating severe disease pressure under untreated conditions. The superior performance of thiophanate methyl + pyraclostrobin and imidacloprid + hexaconazole confirms their strong fungitoxic and systemic action against *S. rolfsii*, consistent with earlier reports demonstrating significant disease reduction through fungicidal seed treatments and integrated modules (Akgul *et al.,* 2011; Hotkar *et al.*, 2026; Vamshi *et al.,* 2025). Among bio-based approaches, the enhanced efficacy of *Trichoderma* with FYM over seed treatment alone suggests improved rhizosphere competence and persistence of antagonists. Organic amendments are known to stimulate microbial activity and create a suppressive soil environment through mechanisms such as competition, antibiosis and induced systemic resistance (Ganesan, 1987; Bonanomi *et al.,*

Table 2: Effect of different treatments on seed germination, stem rot incidence and yield parameters of groundnut conditions during *kharif* 2024 and 2025.

Treatments	Mean germination (%)	Stem rot incidence (%)			Yield (kg/ha)					
		2024	2025	Pooled	Pod yield			Haulm yield		
					2024	2025	Pooled	2024	2025	Pooled
T_1- Seed treatment with (Carboxin 37.5% + Thiram 37.5%) 75 WP @ 3.0 g/kg of seeds + Soil drenching with Tebuconazole 25.9 EC @ 2.0 ml/litre at 60 DAS	90.51	5.32(13.25)*	5.88(13.9)	5.60(13.59)	18.30	18.63	18.47	20.17	22.02	21.10
T_2- Seed treatment with *Trichoderma harzianum* @ 10.0 g/kg seeds	88.89	10.49(18.9)	11.22(19.56)	10.85(19.23)	15.33	16.13	15.73	17.17	17.97	17.57
T_3- Seed treatment with *P. fluorescens* @ 10.0 g/kg seeds	87.49	11.00(19.36)	11.67(19.96)	11.34(19.67)	14.71	15.35	15.03	16.91	17.80	17.36
T_4- Seed treatment with *Trichoderma harzianum* @ 10.0 g/kg seeds + FYM enriched with *Trichoderma harzianum* @ 2.5 kg in 250 kg FYM	88.35	8.89(17.34)	9.56(18.02)	9.22(17.69)	16.70	17.36	17.03	18.97	18.97	18.97
T_5- Seed treatment with *P. fluorescens* @ 10.0 g/kg seeds + FYM enriched with *P. fluorescens* @ 2.5 kg in 250 kg FYM	89.03	9.84(18.27)	10.51(18.92)	10.18(18.61)	16.07	16.95	16.51	18.19	18.19	18.19
T_6- Seed treatment with (Carboxin 37.5% + Thiram 37.5%) 75 WP @ 3.0 g/kg of seeds (Check)	90.16	6.37(14.56)	6.99(15.2)	6.68(14.89)	17.54	17.97	17.75	19.18	21.69	20.44
T_7- Seed treatment with (Thiophanate Methyl 45% + Pyraclostrobin 5%) FS @ 2.0 ml/kg seeds	94.50	3.55(10.76)	3.31(10.42)	3.43(10.59)	20.05	23.32	21.69	22.58	26.26	24.42
T_8- Seed treatment with (Imidacloprid 18.5% + Hexaconazole 1.5% FS) 50 FS @ 1.0 ml/kg seeds	92.35	4.34(12.00)	4.19(11.75)	4.27(11.88)	19.01	22.02	20.52	21.93	24.40	23.16
T_9- Inoculated control	80.33	20.65(27.02)	22.11(28)	21.38(27.52)	12.41	10.82	11.62	14.15	16.40	15.27
S. Em. ±		0.78	1.03	0.87	0.72	1.09	0.82	1.03	1.33	1.04
CD @ 5%		2.36	3.08	2.60	2.16	3.27	2.48	3.08	3.99	3.12
CV (%)		8.05	10.31	8.82	7.50	10.72	8.36	9.49	11.31	9.20

*arc sine transformed values, S. Em.- Standard error of mean, CD- Critical difference, CV- Coefficient of variance.

2018; Meena *et al.,* 2024). Similar results have been reported on other crops such as chickpea (Basamma *et al*., 2021; Sangeeta *et al.,* 2022).

Effect on pod and haulm yield

Pod yield varied significantly among treatments (Table 3), reflecting the impact of disease management on productivity. The highest pooled pod yield was recorded in T_7- [Seed treatment with (Thiophanate Methyl 45% + Pyraclostrobin 5%) FS @ 2.0 ml/kg seeds: 21.69 q/ha], followed by T_8- (Seed treatment with (Imidacloprid 18.5% + Hexaconazole 1.5% FS) 50 FS @ 1.0 ml/kg seeds: 20.52 q/ha) and T_1- Seed treatment with (Carboxin 37.5% + Thiram 37.5%) 75 WP @ 3.0 g/kg of seeds + Soil drenching with Tebuconazole 25.9 EC @ 2.0 ml/litre at 60 DAS (18.47 q/ha). Bioagent-based treatments also resulted in moderate yield improvement, with T_4- (Seed treatment with *Trichoderma harzianum* @ 10.0 g/kg seeds + FYM enriched with *Trichoderma harzianum* @ 2.5 kg in 250 kg FYM: 17.03 q/ha) outperforming T_2- (Seed treatment with *Trichoderma harzianum* @ 10.0 g/kg seeds) and T_3- (Seed treatment with *P. fluorescens* @ 10.0 g/kg seeds). The lowest yield was recorded in the control (11.62 q/ha), indicating substantial yield loss due to disease incidence. A similar trend was observed in haulm yield, where T_7- recorded the highest pooled haulm yield (24.42 q/ha), followed by T_8- (23.16 q/ha) and T_1- (21.10 q/ha). Bioagent treatments showed intermediate performance, while the control recorded the lowest haulm yield (15.27 q/ha), further confirming the adverse effect of disease on plant biomass. The strong reduction in disease incidence corresponded with increased pod and haulm yield, indicating a clear inverse relationship between disease severity and

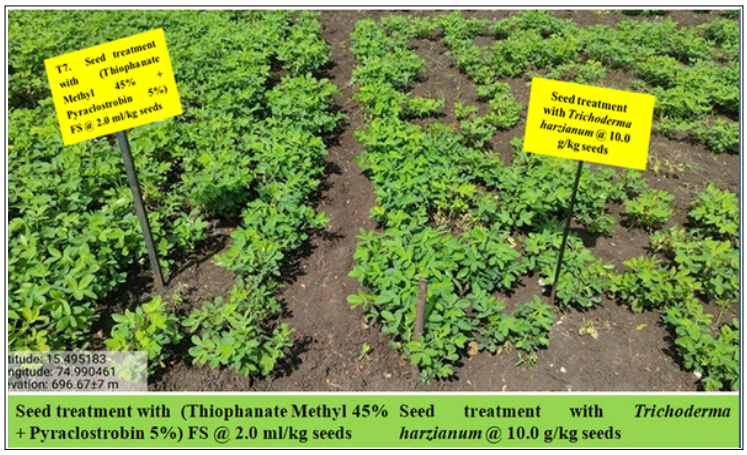


Fig 1a: Performance of selected treatments on stem rot disease incidence in field condition.

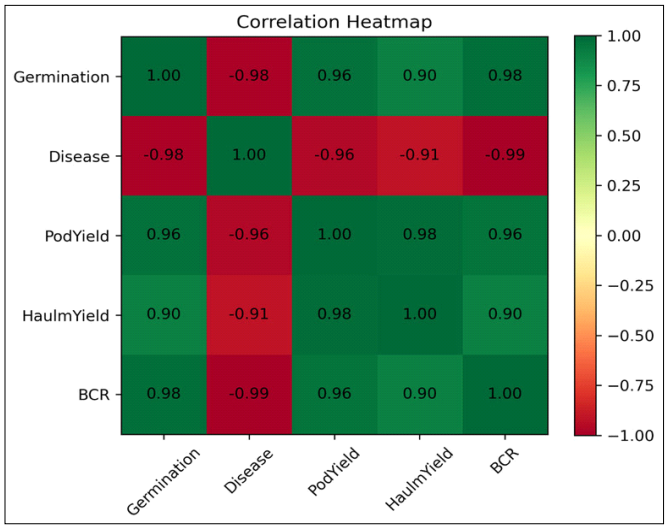


Fig 1b: Correlation heatmap showing relationships among germination, stem rot incidence, pod yield, haulm yield and B:C ratio in groundnut based on pooled data of two seasons.

Table 3: Effect of different treatments on yield and economics of groundnut under field conditions during *kharif* 2024 and 2025.

Treatments	Yield (kg/ha)		Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio
	Pod yield Pooled	Haulm yield Pooled				
T_1- Seed treatment with (Carboxin 37.5% + Thiram 37.5%) 75 WP @ 3.0 g/kg of seeds + Soil drenching with Tebuconazole 25.9 EC @ 2.0 ml/litre at 60 DAS	18.47	21.10	55033	127369.06	72336	2.31
T_2- Seed treatment with *Trichoderma harzianum* @ 10.0 g/kg seeds	15.73	17.57	53132	108430.98	55299	2.04
T_3- Seed treatment with *P. fluorescens* @ 10.0 g/kg seeds	15.03	17.36	53132	103672.98	50541	1.95
T_4- Seed treatment with *Trichoderma harzianum* @ 10.0 g/kg seeds + FYM enriched with *Trichoderma harzianum* @ 2.5 kg in 250 kg FYM	17.03	18.97	54382	117407.09	63025	2.16
T_5- Seed treatment with *P. fluorescens* @ 10.0 g/kg seeds + FYM enriched with *P. fluorescens* @ 2.5 kg in 250 kg FYM	16.51	18.19	54382	113806.33	59424	2.09
T_6- Seed treatment with (Carboxin 37.5% + Thiram 37.5%) 75 WP @ 3.0 g/kg of seeds	17.75	20.44	53692	122455.65	68764	2.28
T_7- Seed treatment with (Thiophanate Methyl 45% + Pyraclostrobin 5%) FS @ 2.0 ml/kg seeds	21.69	24.42	53832	149537.21	95705	2.78
T_8- Seed treatment with (Imidacloprid 18.5% + Hexaconazole 1.5% FS) 50 FS @ 1.0 ml/kg seeds	20.52	23.16	53832	141475.46	87643	2.63
T_9- Inoculated control	11.62	15.27	52882	80337.99	27456	1.52
S. Em. ±	0.82	1.04				
CD @ 5%	2.48	3.12				
CV (%)	8.36	9.20				

productivity, which has been widely reported in groundnut pathosystems (Punja, 1985; Bosamia *et al.,* 2020; Deepika *et al.,* 2025).

Economic analysis

Economic evaluation (Table 3) revealed that T_1- Seed treatment with (Carboxin 37.5% + Thiram 37.5%) 75WP @ 3.0 g/kg of seeds + Soil drenching with Tebuconazole 25.9EC @ 2.0 ml/litre at 60 DAS recorded the highest benefit-cost ratio (2.31), followed by T_2- (Seed treatment with *Trichoderma harzianum* @ 10.0 g/kg seeds; 2.04) and T_3- (Seed treatment with *P. fluorescens* @ 10.0 g/kg seeds: 1.95), indicating better economic feasibility of integrated and bioagent-based treatments despite slightly lower yields compared to fungicides. Treatments involving fungicides showed higher yields but relatively higher input costs. The lowest returns were recorded in the control, reflecting the economic loss associated with unmanaged disease conditions.

Although fungicides recorded maximum yield, bioagent-based and integrated treatments showed competitive economic returns due to lower input costs and sustained disease suppression. Recent studies emphasize that integrated disease management strategies combining chemical, biological and organic approaches provide more stable and sustainable control of soil-borne pathogens (Bonanomi *et al.,* 2018; Ayyandurai *et al.,* 2023; Vamshi *et al.,* 2025; Hotkar *et al.,* 2026). Overall, the findings confirm that integration of fungicides with bioagents and organic amendments offers an effective and sustainable approach for managing stem rot and seed rot of groundnut under field conditions.

Correlation analysis

A strong and highly significant relationship was observed among disease incidence, yield and economic parameters (Fig 1b). Stem rot incidence exhibited a very strong negative correlation with germination (r = -0.98), pod yield (r = -0.96), haulm yield (r = -0.91) and B:C ratio (r = -0.99), indicating that increased disease severity drastically reduces plant establishment, productivity and profitability. Similar correlation patterns between disease severity and yield loss have been reported in groundnut and other crops (Punja, 1985; Bosamia *et al.*, 2020; Meena *et al.*, 2024). Germination showed a strong positive correlation with pod yield (r = 0.96) and B:C ratio (r = 0.98), suggesting that early-stage seed health plays a crucial role in determining final yield and economic returns. Similarly, pod yield was highly correlated with haulm yield (r = 0.98), reflecting uniform biomass accumulation under effective disease management. The near-perfect negative association between disease incidence and B: C ratio (r = -0.99) highlights that economic losses in groundnut are primarily driven by disease pressure. Overall, the results clearly indicate that disease suppression is the central determinant of yield and profitability, confirming the effectiveness of integrated treatments in improving crop performance.

Simple regression analysis (Disease vs Pod yield)

A strong negative linear relationship was observed between stem rot incidence and pod yield, indicating that disease severity is a major determinant of productivity (Fig 2). The regression model suggests that each unit increase in disease incidence leads to a substantial decline in yield, highlighting the critical importance of effective disease management. The high coefficient of determination (R^2 > 0.90) confirms that variation in yield is largely explained by disease incidence. Slope of -0.53 indicates that for every 1% increase in disease, yield reduces by 0.53 q/ha. Such linear relationships between disease intensity and yield loss have been widely documented in soil-borne pathosystems (Akgul *et al.,* 2011; Bosamia *et al.*, 2020).

Equation

$$\text{Pod yield} = 22.04 - 0.53 \times \text{Disease incidence}$$

Disease-yield loss model

A strong positive linear relationship was observed between stem rot incidence and relative yield loss, indicating that increasing disease severity significantly reduces crop productivity (Fig 3). The regression model showed that each unit increase in disease incidence resulted in a proportional increase in yield loss, with a high coefficient of determination ($R^2 \approx 0.92$), confirming the strong influence of disease on yield reduction. This model quantitatively establishes stem rot as a major limiting factor in groundnut production.

Multiple regressions

Multiple regression analysis revealed that pod yield was strongly explained by the combined influence of germination, disease incidence, haulm yield and B:C ratio, with a very high coefficient of determination (R^2 = 0.993), indicating that 99.3% of the variability in yield was accounted for by these variables (Fig 4). The fitted model (Pod yield = -20.67 + 0.27 ×Germination + 0.005 × Disease + 0.60 × Haulm yield + 1.02 × B:C) indicated that haulm yield exerted

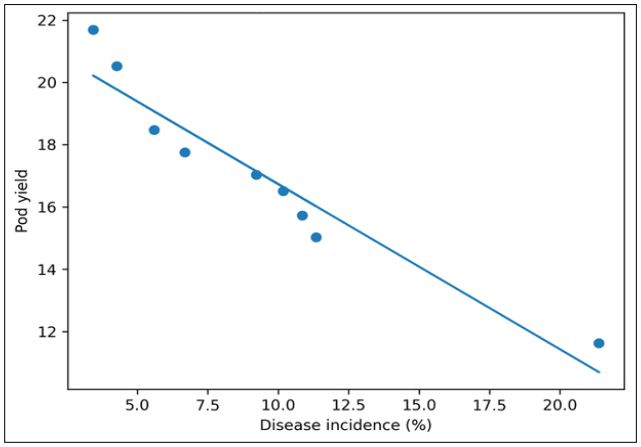


Fig 2: Relationship between stem rot incidence (%) and pod yield (q ha^{-1}) in groundnut under different treatments.

the most significant positive effect on pod yield (p = 0.004), highlighting biomass production as the primary determinant of yield under disease-managed conditions. Germination showed a positive but moderate contribution, suggesting the importance of early crop establishment. Although disease incidence exhibited a negligible coefficient in the model, this is attributed to strong interrelationships among variables (multicollinearity), as disease effects were indirectly expressed through their influence on germination and yield components. The B:C ratio did not show a direct predictive role due to its dependence on yield. Overall, the results indicate that yield performance is predominantly governed by biomass accumulation and indirectly influenced by disease suppression and crop establishment. This suggests that disease impacts yield primarily through its influence on plant growth and development rather than direct yield reduction, which is consistent with findings of Meena *et al.* (2024) and Vamshi *et al.* (2025).

Equation

Pod yield = -20.67 + 0.27 (Germination) + 0.005 (Disease) + 0.60 (Haulm yield) + 1.02 (B:C)

PCA (Principal component analysis)

Principal component analysis (Fig 5) revealed that most of the variability among treatments was explained by the first principal component (PC1; 96.16%), indicating strong interdependence among measured traits. Positive loadings of germination, pod yield, haulm yield and B:C ratio on PC1, along with negative loading of disease incidence, clearly indicate that these variables are inversely related to disease severity.

Treatments with lower disease incidence were clustered on the positive side of PC1, associated with higher yield and economic returns, whereas the control treatment was distinctly separated due to higher disease pressure

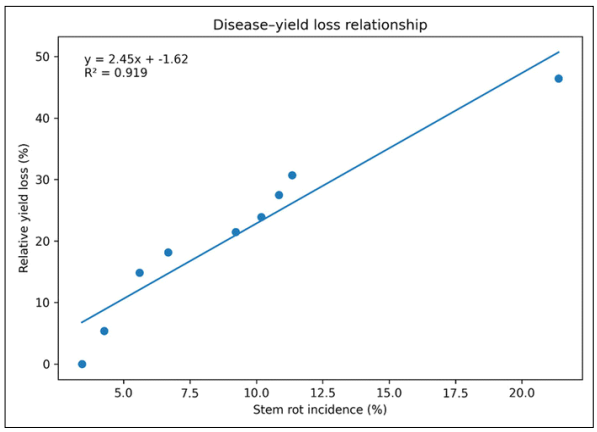


Fig 3: Relationship between stem rot incidence (%) and relative yield loss (%) in groundnut showing a strong positive linear association, based on pooled data of two seasons.

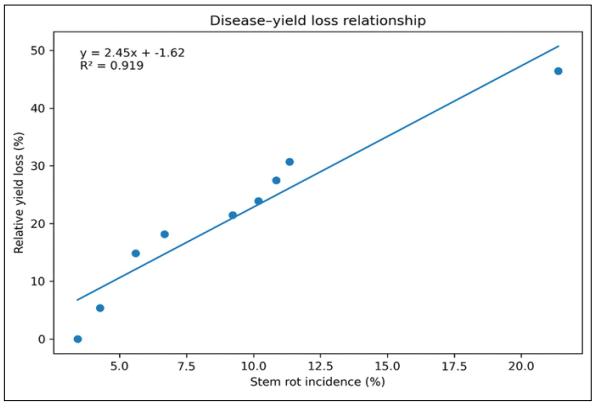


Fig 4: The plot of observed versus predicted pod yield showed a close alignment along the 1:1 line, indicating high predictive accuracy of the multiple regression model and confirming the robustness of the relationship among the studied variables.

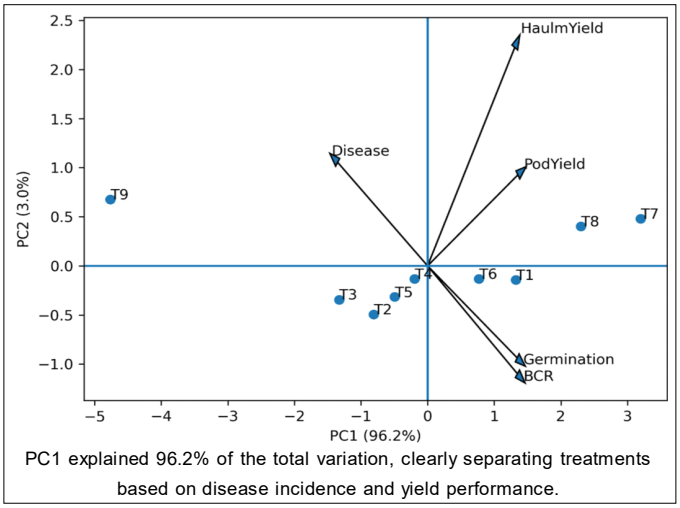


Fig 5: Principal component analysis (PCA) biplot showing the relationship among germination, stem rot incidence, pod yield, haulm yield and B: C ratio.

and lower performance. This pattern confirms that disease suppression is the primary factor governing treatment differentiation and crop productivity. Similar multivariate patterns have been reported in disease management studies, where yield and disease parameters cluster along opposite axes (Bosamia *et al.*, 2020; Deepika *et al.,* 2025).

Cluster analysis (Dendrogram)

Hierarchical cluster analysis grouped the treatments into distinct clusters based on their overall performance. High-performing treatments (T_7, T_8, T_1 and T_6) were clustered together, indicating similarity in terms of higher germination, lower disease incidence and superior yield. Moderate treatments (T_2, T_3, T_4 and T_5) formed a separate cluster, while the control (T_9) was distinctly separated, reflecting its poor performance. This clustering clearly demonstrates treatment differentiation and validates the superiority of integrated and fungicidal treatments. This clustering reflects treatment efficiency and supports the concept of integrated disease management, as reported by Hotkar *et al.* (2026) and Vamshi *et al.* (2025).

CONCLUSION

The stem rot significantly affects germination, plant growth, yield and economic returns in groundnut under field conditions. Effective disease management resulted in improved seedling establishment, reduced disease incidence and enhanced productivity. Among the treatments evaluated, T_7 (Seed treatment with (Thiophanate Methyl 45% + Pyraclostrobin 5%) FS @ 2.0 ml/kg seeds) and T_8 (Seed treatment with (Imidacloprid 18.5% + Hexaconazole 1.5% FS) 50 FS @ 1.0 ml/kg seeds) consistently recorded lower stem rot incidence, higher germination, superior pod and haulm yield and better economic returns, indicating their effectiveness under disease pressure. Correlation and regression analyses confirmed that disease incidence was negatively associated with yield and related parameters, establishing it as the primary limiting factor in crop productivity. The disease-yield loss model further quantified this relationship, indicating that even small increases in disease severity result in substantial yield loss. Multiple regression and path analysis revealed that haulm yield was the most influential factor contributing to pod yield, while the effect of disease was largely indirect through its influence on plant growth and development. Multivariate analyses, including PCA indicated strong interrelationships among germination, yield and economic traits, with disease incidence showing an opposite trend. Cluster analysis and combined performance index clearly differentiated treatments, identifying T_7 (Seed treatment with (Thiophanate Methyl 45% + Pyraclostrobin 5%) FS @ 2.0 ml/kg seeds), T_8 (Seed treatment with (Imidacloprid 18.5% + Hexaconazole 1.5% FS) 50 FS @ 1.0 ml/kg seeds) and T_1 (Seed treatment with (Carboxin 37.5% + Thiram 37.5%) 75WP @ 3.0 g/kg of seeds + Soil drenching with Tebuconazole 25.9 EC @ 2.0 ml/litre at 60 DAS) as superior treatments. In contrast, the inoculated control was statistically separated into an independent cluster, exhibiting significantly higher stem rot incidence and significantly lower yield and economic parameters ($P \leq 0.05$) compared to all treated plots, confirming its inferior performance under disease pressure. Overall, the study highlights that effective management of stem rot is essential for improving yield and profitability in groundnut. Integrated management approaches combining chemical and biological strategies (*Trichoderma* sp. seed treatment @10 g/kg seeds and enriched FYM with *Trichoderma* @ 2.5 kg/250 kg FYM) proved more effective and sustainable compared to individual methods. Multivariate and regression-based analyses consistently indicated that disease suppression is the primary determinant of yield and economic performance. The findings provide a comprehensive understanding of disease-yield relationships and offer a scientifically validated basis for selecting effective management practices under field conditions.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

Not applicable.

Conflict of interest

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REFERENCES

Akgul, D.S., Ozgonen, H. and Erkilic, A. (2011). The effects of soil solarization and some organic amendments on *Sclerotium rolfsii* Sacc. causing stem rot in peanut. *Crop Protection.* **30:** 178-183.

Ayyandurai, M., Akila, R., Manonmani, K., Mini, M.L., Vellaikumar, S., Brindhadevi, S. and Theradimani, M. (2023). Combined application of *Trichoderma longibrachiatum* T(SP)-20 and *Trichoderma asperellum* T(AR)-10 in the management of stem rot of groundnut. *Legume Research.* **46(2):** 215-221. doi: 10.18805/LR-4781.

Ayyandurai, M., Nakkeeran, S. and Samiyappan, R. (2022). Biological management of stem rot disease of groundnut caused by *Sclerotium rolfsii*. *Madras Agricultural Journal.* **109:** 1-7.

Basamma, K., Balol, G., Lokesh, B.K., Kukanur, S. and Nayak, H. (2021). Field evaluation of different fungicides against *Uromyces ciceris-arietini* causing rust in chickpea in northern Karnataka. *Journal of Pharmacognosy and Phytochemistry*. **10(1):** 896-900.

Bhupender, K.A., Kumari, K., Kumari, S. and Singh, K.M. (2020). An economic analysis of production and marketing of clusterbean in Rajasthan. *Multilogic in Science*. **10 (35):** 1210-1216.

Bonanomi, G., De Filippis, F., Cesarano, G., La Storia, A., Ercolini, D. and Scala, F. (2018). Organic amendments modulate soil microbiota and reduce pathogen incidence in agricultural soils. *Applied Soil Ecology*. **129:** 70-85.

Bosamia, T.C., Thankappan, R., Dobaria, J. R. and Mishra, G.P. (2020). Insights into the biology and management of *Sclerotium rolfsii* causing stem rot of groundnut. *Plant Pathology Journal*. **36:** 1-15.

Deepika, B., Sheela, J., Indra, N., Kalaiyarasi, R. and Navamaniraj, K.N. (2025). Integrated approach for managing groundnut stem rot caused by *Sclerotium rolfsii* Sacc. *Plant Science Today*. **2:** 1-12.

Ganesan, S. (1987). Biological control of *Sclerotium rolfsii* Sacc. in groundnut using *Trichoderma* spp. *Soil Biology and Biochemistry*. **19:** 35-38.

Hotkar, S., Ashtaputre, S.A., Jahadirdar, S., Rao, M.S.L., Motagi, B.N. and Jones, P. (2026). Integrated management of stem rot of groundnut caused by *Sclerotium rolfsii* Sacc. through fungicides, bioagents and organic manures. *Legume Research-An International Journal*. **49(3):** 522-528. doi: 10.18805/LR-5506.

Jacob, S., Sajeshkumar, N.K. and Thankappan, R. (2018). Management of soil-borne diseases of groundnut using *Trichoderma* spp. and *Pseudomonas fluorescens*. *Journal of Plant Protection Research*. **58:** 123-130.

Kushwah, A.S., Rawat, G.S., Gupta, S., Patil, D. and Prajapati, N. (2017). Production and profitability assessment of clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.] based intercropping systems under different row arrangement. *Legume Research- An International Journal*. **40(5):** 916-919. doi: 10.18805/LR-3809.

Meena, M., Swapnil, P., Divyanshu, K., Kumar, S. and Tripathi, Y. N. (2024). Role of biological control agents in managing soil-borne plant pathogens. *Biological Control.* **182:** 105-118.

Mehan, V.K., McDonald, D. and Ramakrishna, N. (1994). The groundnut root rot complex: Occurrence, distribution and management. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Bulletin.

Nathawat, B.D.S., Dinesh, K., Rakesh, K., Ravinder, K. and Choudhary, R.R. (2025). Management of collar rot disease in groundnut (*Arachis hypogaea* L.) caused by *Aspergillus niger* in Rajasthan through biocontrol agents. *Legume Research-An International Journal*. **48(12):** 2117-2121. doi: 10.18805/LR-5222.

Panse, V.G. and Sukhatme, P.V. (1985). Statistical Methods for Agricultural Research Workers, ICAR, New Delhi

Punja, Z.K. (1985). The biology, ecology and control of *Sclerotium rolfsii*. *Annual Review of Phytopathology*. **23:** 97-127.

Sangeeta, N., Prabhu, H.V. and Balol, G. (2022). *In vitro* evaluations of fungicides against *Sclerotium rolfsii* Sacc. causing collar rot of chickpea. *International Journal of Plant Sciences*. **17(2):** 163-166.

Vamshi, J., Devi, G.U., Sudini, H.K., Gireesha, D., Priya, K.K.V., Maheswari, T.U. and Supriya, K. (2025). Impact of carbon dioxide levels on biochemical parameters associated with stem rot disease in groundnut. *Indian Journal of Agricultural Research*. **59(7):** 1149-1156. doi: 10.18805/IJARe.A-6333.

Vamshi, J., Devi, G.U., Somraj, B., Maheswari, T.U., Supriya, K. and Sudini, H.K. (2025). Biocontrol efficacy of *Trichoderma* and *Bacillus* isolates against *Sclerotium rolfsii* under *in vitro* conditions. *Legume Research.* **48(11):** 1846-1854. doi: 10.18805/LR-5414.