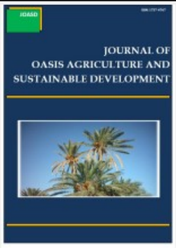

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Bio-control management of foot and root rot disease of lentil as impacted by different formulations of *Trichoderma* product

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Abstract

Foot and root rot disease, caused by *Fusarium oxysporum* and *Sclerotium rolfsii*, is one of the most devastating lentil diseases, resulting in decreased yield. A study was done to assess the efficacy of several *Trichoderma* formulated products in treating lentil foot and root rot disease as a biocontrol agent. The study used a Randomized Complete Block Design (RCBD), with seven treatments, viz., T1 = Control, T2 = Decoprima, T3 = Lycomax, T4 = Dynamic, T5 = Tricost, T6 = Provax 200 WP, and T7 = Trichoderma. All treatments were applied as seed treatments and sprays to the plant's basal region (root zone). Data were obtained on several days following the sowing dates. The findings showed that the numerous treatments used had a considerable impact on yield, contributing features, and growth indices. T3 (Lycomax) showed promising results in reducing lentil overcontrol disease among foot and root infection treatments. The disease incidence was lowest in T3 (15.23%) and highest (31.25%) in the control group. T3 also exhibited the highest plant height, branches/plant, nodules/plant, pods/plant, root length/plant, and yield compared to the control. Given the performance of the biocontrol agents assessed in the study, Lycomax might be recommended for producers to treat their seed and use basal spraying of this biocontrol agent to manage foot and root rot of lentil.

1. INTRODUCTION

Lentil (*Lens culinaris* Medik) is the second-top pulse crop in Bangladesh in terms of cultivating area and productivity; additionally, it is the most preferred pulse among consumers (Uddin et al., 2008). Lentils are popularly known as Masur in Bangladesh, and this pulse crop belongs to the subfamily Papilionaceae under the family Leguminosae. Lentil ranks as the third-most significant cool-season grain legume in worldwide production, following chickpea and pea (Sehgal et al., 2021). In Bangladesh, lentils are cultivated on approximately 351,930 acres, yielding around 175,384 metric tons annually (BBS, 2019). In 2018-2019, Bangladesh produced a total of 175,384 tons of lentils from 351,930 hectares, with an average yield of 0.4984 t/ha (BBS, 2020).

It holds a unique position in global agriculture due to its higher protein concentration and ability for Rhizobium bacteria to fix atmospheric nitrogen in root nodules (Awal and Roy, 2015). Lentil is a legume plant that is rich in fiber but relatively low in fat (Jarpa - Parra, 2018). It also contains more total soluble fiber than peas and chickpeas (Brummer et al., 2015). Currently, it is one of the primary sources of protein for approximately half of the global population; moreover, it is most extensively consumed in the developing world (Stefaniak and McPhee, 2015).

The yield of pulse crops, especially lentils, is considerably lower in Bangladesh compared to other lentil-producing countries such as Syria, Turkey, Ukraine, Canada, the USA, and Ethiopia. A main factor contributing to this poor yield is the prevalence of diseases, which might result in a 30 to 40% production decline. Additionally, among the most destructive diseases of lentils are foot and root rot, caused by soil-borne pathogens, namely Fusarium oxysporum and Sclerotium rolfsii, which can contribute to up to 100% mortality of seedlings (Begum, 2003; Al Masum et al., 2025).

Traditionally, chemical or synthetic management has been employed to combat these diseases; however, these methods are expensive, time-consuming, environmentally harmful, and damaging to beneficial microbes. As an alternative, biological control is now recognized as a promising method. Employing bio-treatments such as Trichoderma spp. offers an intriguing strategy owing to their adaptability, rapid expansion, and vast antibiotic spectrum; moreover, these bio-fungicides effectively control soil-borne pathogens such as Fusarium, Pythium, Phytophthora, and Rhizoctonia solani, thus contributing to agricultural sustainability (Karim et al., 2024a; Ali et al., 2025).

The global imminent danger linked with contamination and degradation of the environment and health hazards posing toxicity to humans, plants, domestic animals, and wildlife makes chemical-based solutions environmentally unsustainable. In this context, Trichoderma is a highly effective and appealing biological control agent, as well as an alternative to traditional fungicides. These Trichoderma-based biocontrol agents and organic manure-based fertilizers are economically viable and sustainable for the environment, and they represent the most effective way to maintain the current level of crop production (Mishra et al., 2020; Rahman et al., 2024; Laboni et al., 2024).

Despite the potential of biocontrol methods, limited research has been undertaken in Bangladesh, particularly with regard to the controlling of foot and root rot in lentils. Furthermore, an evaluation of the efficiency of commercially formulated biocontrol pesticides in field conditions will be required to develop an ecologically sound management strategy for combating these diseases in lentils.

2. MATERIAL AND METHODS

2.1 Experimental Setup

The experiment was carried out during the Rabi season of Bangladesh, from November 2021 to March 2022, at the Plant Pathology Research Field of Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur. The experimental field was medium-high land with sandy loam soil texture. The pH of the experimental plot was 5.2. Soil general characteristics and physical and chemical constituents of the experimental plot were analyzed by the Soil Resource Development Institute and are represented in Table 1.

In addition to the parameters listed in Table 1, the experimental soil had moderate fertility and a slightly acidic pH (5.20). The organic carbon content (0.72%) and total nitrogen (0.08%) suggest moderate organic matter status. The available phosphorus (11.2 ppm) and sulfur (17.29 ppm) levels were adequate for lentil growth, while exchangeable calcium (2.48 meq) and magnesium (2.29 meq) indicated a well-balanced base saturation. Although the soil microbiome was not directly assessed in this study, the Old Himalayan Piedmont Plain (AEZ-1) is generally known to harbor diverse rhizospheric microbial communities, including native strains of *Trichoderma, Bacillus*, and *Pseudomonas*, which may synergistically interact with applied biocontrol agents.

The climate of the experimental site was subtropical in nature, defined by three different seasons. The rainy period extended from May to September, the winter or dry period from October to February, and the pre-monsoon or hot season from March to April. The rainy season was marked by heavy rainfall, but the remainder of the year had little rain. Weather conditions during the conduction of research of the experimental area were recorded and depicted in Fig. 1.

The experiment used the lentil (*Lens culinaris*) variety BARI Masur 8, which was released by the Bangladesh Agricultural Research Institute (BARI) in Joydevpur, Gazipur. Seeds were taken from Rajbari Agricultural Farm in Dinajpur.

An area of medium-high ground with a good drainage system was chosen for lentil farming. Before seeding, the experimental land was thoroughly plowed, cross-plowed, and cleaned. The following operations were carried out with a harrow, a spade, a hammer, etc. The clods were broken up into fine soil particles, and the surface was smoothed until the desired tilth was achieved. Weeds and stubble were removed, and the experimental design was used for final preparation. Seven treatments, viz., T2 = seed treatment with Decoprima and spraying at the basal region of the plant, T3 = seed treatment

Table 1. Soil general characteristics and physical and chemical constituents of the experimental plot.

Category	Properties	Value / Characteristics
A. Site and Soil Classification	Agro-ecological zone	Old Himalayan Piedmont Plain (AEZ-1)
	Geographical position	25°38′N latitude and 88°41′E longitude
	General soil type	Non-calcareous dark grey floodplain
	Elevation	37 meters above mean sea level
B. Soil Physical Properties	Soil texture	Sandy loam
	Sand (%)	62
	Silt (%)	24
	Clay (%)	14
	pH	5.20
	Cation exchange capacity (CEC, meq/100g)	12.4
C. Soil Chemical Properties	Organic carbon (%)	0.72
	Total nitrogen (%)	0.08
	Available phosphorus (P, ppm)	11.2
	Available potassium (K, meq/100g)	0.18
	Exchangeable calcium (Ca, meq/100g)	2.48
	Exchangeable magnesium (Mg, meq/100g)	2.29
	Available sulfur (S, ppm)	17.29
D. Micronutrient Status	Available zinc (Zn, ppm)	0.72
	Available boron (B, ppm)	0.23
	Available molybdenum (Mo, ppm)	0.05
E. Microbial Status	Microbial activity	Moderate; dominant genera include *Trichoderma*, *Pseudomonas*, *Bacillus*, and *Azotobacter*

Source: *Results obtained from SRDI, Dinajpur, and literature-based microbial profile for AEZ-1.*

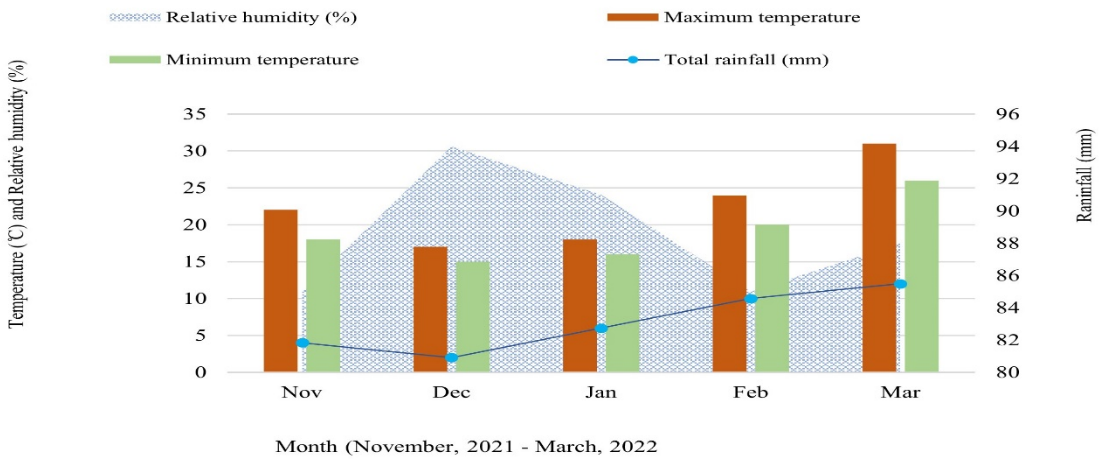

Fig. 1. Monthly (November 2021 - March 2022) measurements of maximum and minimum temperature, relative humidity, and rainfall of the experimental area.

with Lycomax and spraying at the basal region of the plant, T4 = seed treatment with Dynamic and spraying at the basal region of the plant, T5 = seed treatment with Tricost and spraying at the basal region of the plant, T6 = seed treatment with Provax 200 WP and spraying at the basal region of the plant, and T7 = seed treatment with Trichoderma, were evaluated against T1 = control.

Following final land preparation, the field layout was completed. The experiment was set up in a Randomized Complete Block Design (RCBD), with three replications. The field was divided into three blocks, each with seven (7) plots of 2m x 1m size, totaling 21 plots. The spacing between rows and plants (inside the plot) was 30 cm and 6 cm, respectively. The block-to-block distance was kept at one meter. The distance between plots was 0.5 m, and each plot included four rows. Seeds were sown in lines in the experimental plots. The seeds were sown around 3 cm deep in the soil. For seed treatment, 50 g of seeds were extracted from each plot and combined with the appropriate amount of each of the six treatments separately. In the case of Decoprima, 0.14 g was collected; 0.75 g Lycomax, 0.5 g Dynamic WP, 1 g Tricost 1% WP, 1 g Trichoderma, and 0.75 g Provax 200 WP were taken into the conical flask individually, and 50 g seeds were introduced with each treatment, then shaken thoroughly to mix with the bio-fungicides/fungicide. Each treatment was administered in a separate conical flask. Following this, the seeds were ready to sow. Seeds that were healthy and disease-free were sown in the experimental field. 50g of seeds were sown in lines in each experimental plot ($2m^2$). Lentil seeds were spread in rows on November 28, 2021, using a continuous seeding method. The row-to-row distance was 30 cm, and the sowing depth was 2-3 cm.

2.2. Application of Bio-fungicides/fungicides

A bio-fungicidal/fungicidal solution was created by dissolving a specific amount of the bio-fungicides/fungicides in the appropriate amount of plain water (Table 2). Bio-fungicides/fungicides were applied three times throughout the research period. Spraying was carried out using a hand sprayer every 15 days. During spraying, the fungicidal solution was carefully applied to the plant's base region to ensure complete coverage. The spray tank was cleaned before filling with fungicidal solution materials.

2.3. Identification and confirmation of foot and root rot

Foot and root rot-affected lentil plants caused by Fusarium oxysporum and Sclerotium rolfsii displayed many indications and symptoms, such as, firstly, the first evident field symptom had appeared at the soil level at the base of the stem/collar region, with light brown to black discoloration and decay spreading to the top leaves and eventually enveloping the entire plant. In severe stages of disease development, the stem, leaf, and entire plant wilted, dried, and died. White mycelia or sclerotia had been found in the affected area of the plant. Then the affected plants and plant parts were collected

Table 2. Details of the fungicides applied.

Common name	Active ingredient	Formulation	Amount (g/L of water)	Source/Company
Decoprima	*Trichoderma* sp. 4,35× 105 cfu/g *Streptomyces* sp. 1,16 × 106 cfu/g *Geobacillus* sp. 1,94×106 cfu/g	Powder	0.14 g	Mohsin Enterprise
Lycomax	*Trichoderma harzianum* 2-3% *Trichoderma viride* 0.5-1% *Metarhizium anisopliac* 2-3% *Beauveria bassiana* 2-3%	Powder	0.75 g	Russell IPM UK Ltd.,
Dynamic WP	*Bacillus amyloliquefaciens* 1×106 cfu/g	Powder	0.5 g	Russell IPM UK Ltd.,
Tricost 1% WP	*Trichoderma* 2×106 cfu/g	Powder	1 g	Haychem (Bangladesh) Limited
Provax 200 WP	Carboxin 37.50% + Thiram 37.50%	Powder	0.75 g	Local Market of Dinajpur
Trichoderma	*Trichoderma*	Powder	1 g	Trichoderma Laboratory, RDA, Bogura

and covered in a plastic bag and sent to the laboratory of Plant Pathology of Hajee Mohammad Danesh Science and Technology University, Dinajpur, for the isolation, bacterial culture and identification, and confirmation of Fusarium oxysporum and Sclerotium rolfsii under the microscope.

To confirm the presence of Fusarium oxysporum and Sclerotium rolfsii, infected root and collar tissues were surface sterilized using 1% sodium hypochlorite solution for 2 minutes, followed by triple rinsing with sterile distilled water and blot drying. The tissues were then placed on Potato Dextrose Agar (PDA) plates and incubated at 25 ± 2°C for 5–7 days. Colony morphology was observed: Fusarium oxysporum produced cottony white to pinkish mycelia with sickle-shaped macroconidia and abundant microconidia, while Sclerotium rolfsii formed fast-growing white mycelia with light brown spherical sclerotia. Identification was further verified through microscopic examination using standard taxonomic keys (Agrios, 2005).

2.4. Data collection

Plant growth parameters and disease data were gathered four times, beginning at 40 days after sowing (DAS) and progressing at 15-day intervals. During the growth season, lentil plots were inspected on a regular basis to monitor foot and root rot disease as well as many agronomic indicators. Ten plants were randomly selected from each plot, and the number of branches per plant was counted. Plant height was measured in cm using a meter scale during both the vegetative and reproductive stages of plant development. Ten plants were randomly picked from each plot to be measured for height. Visual observation was used to determine the total number of diseased/infected plants at various stages of growth. The data on the total number of diseased plants per plot were collected 40 days following seeding. Each plant was tallied, as well as the infected plants inside each treatment's observation area, and the results were represented as a percentage. Disease incidence (%) was estimated using the following formula (Agrios, 2005; Howlader et al., 2024; Hasan et al., 2025):

Disease incidence (%) =

(Number of infected plants)/(Total number of inspected plants) × 100

The total number of nodules on selected plants from each plot was counted at 70 and 85 days after sowing, and data were recorded as the average of 10 plants chosen at random from the plot's inner rows. The total number of pods of selected plants from each plot was counted at 70 and 85 days, and data were recorded as the average of 10 plants chosen at random from each plot's inner rows. When the plants in the experimental field reached 80% to 90% maturity, as measured by straw color, pod filling, pod color, water content per plant, and other indicators. At maturity, the total number of plants in each plot was collected and labeled according to plot identity. Data gathering involved harvesting 27 plots independently. The lentils were allowed to dry on the threshing floor for four days before being manually threshed. The clean seeds were sun-dried for three days to reach a moisture level of 9-10%. To protect the seeds from bruchids, they were stored in proper bins and refrigerators. The total harvested grains per plot were weighed to determine yield. The yield was measured in grams (g) (Hasan et al., 2025; Bashir et al., 2025).

2.5 Statistical analysis

The data collected from various factors was appropriately compiled and organized in Excel spreadsheets. The Statistix-10 computer package program performed appropriate statistical analysis. The treatment means were tested against the LSD (Least Significant Difference) value at $\alpha = 0.05$.

3. RESULTS AND DISCUSSION

3.1 Effect of different treatments on plant height

Plant height differed significantly among the treatments. Seven treatments were compared with each other for plant height noted at 40, 55, 70, and 85 days after sowing (DAS). At 40 DAS, the lowest plant height (4.33 cm) was observed in the control treatment (T1), where T3 (Lycomax) showed the highest plant height, which was 9.33 cm, followed by T6 (7.33) and T4 (6.33), as shown in Table 3. At 55 DAS, similar trends of results were obtained, where the lowest plant height was filed in T1 (21.33 cm) and the highest plant height (27.66 cm) was recorded in T3 (Lycomax) treatment (Table 3). At 70 DAS, similar trends of results were found, where the lowest plant height was recorded in T1 (31 cm) and the highest plant height (35.66 cm) was recorded in T3 (Lycomax) treatment. At 85 DAS, the final plant height was recorded, and it showed the maximal plant height at T3 (Lycomax), and the minimal plant height (32.66

Table 3. Effect of treatments on plant height/plot and numbers of branch/plant of lentil at different days of data collection.

Treatments	Plant height (cm)				Numbers of branch/plant			
	40 DAS	55 DAS	70 DAS	85 DAS	40 DAS	55 DAS	70 DAS	85 DAS
T1	4.33 d	21.33 e	31.00 e	32.66 f	2.33 c	4.33 d	6.66 f	6.66 e
T2	5.33 cd	22.33 de	32 de	34 e	3 bc	5 cd	8 e	8.66 de
T3	9.33 a	27.66 a	35.66 a	39.66 a	4.66 a	7.33 a	11.66 a	12.66 a
T4	6.33 bc	24.66 c	34 bc	36.33 c	3.66 ab	5.66 bc	10.33 bc	10.66 bc
T5	5.66 c	23.33 d	33cd	35.33 d	3.00 bc	5.33 c	9.33 cd	9.66 c
T6	7.33 b	26.33 b	34.66 ab	37.66 b	4 ab	6.33 b	10.66 ab	11.66 ab
T7	5.33 cd	22.66 d	32.66 d	34.33 e	3.33 bc	5.00 cd	8.66 de	8.33 d
%CV	9.58	2.57	2.12	1.37	16.43	9.05	7.52	6.21

Means having same letter within a column do not differ significantly at 5% level of probability.

cm) was recorded in the control treatment (T1). Thus, Lycomax (T3) treatment showed the comparatively best result among other applied treatments in the case of plant height of lentil plants against foot and root rot disease of lentils. The absolute average plant height was recorded from the T3 treatment, which was followed by T6 and T4, and the shortest average plant height was recorded in T1. Plant height of lentil gradually increased with increasing age of plant. Plant height was significantly varied among the treatments during all dates of data collection. The maximum plant height was recorded at the bio-fungicide-treated plot compared to the control plot. Increasing plant height may contribute to lentil yield. Among the bio-fungicides, Lycomax showed the best effective performance for the highest number of plant heights, and then the chemical treatment Provax 200 WP also showed an effective result, followed by the other treatment for plant height of lentil. According to Mohbe et al. (2018), poultry manure demonstrated the best performance in initial plant height at 15 DAS, pod formation, and maximum seed yield per green gram plot. Kadiri and Mustapha (2010) reported that spent mushroom substrate compost (SMS) mixed with loamy soil produced significantly greater plant height and stem girth of cowpea.

3.2 Effect of different treatments on numbers of branch/plant

The number of branches per plant was counted by visual observation at 40, 55, 70, and 85 days after sowing (DAS), and the data were presented at Table 2. At 40 DAS, the lowest number of branches (2.33 cm) was noted in the control treatment (T1), where T3 (Lycomax) provided the highest number of branches, which was 4.66 cm, followed by T6 (4 cm), as shown in Table 1. At 55 DAS, maximum numbers of branches/plants were recorded from T3 (7.33 cm), which was followed by T6, and minimum branches were recorded from T1 (4.33 cm), which was similar to T2 (5.00 cm) and T7 (5.00 cm). At 70 DAS, the highest number of branches/plants was reported in T3 (11.66 cm), which was similar to the T6, and the lowest number of branches/plants was noted in T1 (6.66 cm). At 85 DAS, the final number of branches was recorded, and T3 (Lycomax) showed the highest number of branches (6.66 cm), and the lowest number of branches (12.66 cm) was recorded in the control treatment (T1). Thus, Lycomax (T3) treatment showed the best result in case of number of branches of lentil plant against foot and root rot disease of lentil. Results of the present study showed that the maximum number of plant branches was recorded in treated plants compared to untreated control plants. Bio-fungicide-treated plants always showed better performance in plant growth parameters. Among the treatments, T3 showed the maximum number of branches/plants treated through Lycomax. Results were also supported by Kashem *et al.* (2011), who reported that ten bioagents, including a control, were tested in these experiments. They suggested applying macerated extract of *Fusarium solani* + *Trichoderma harzianum*, which showed the best result in controlling root rot of lentils with the highest seed germination (100%) and number of branches/five plants (15.56).

3.3 Effect of different treatments on percent disease incidence

At 40 DAS, the highest (20.07%) disease incidence was observed in treatment T1 (control), whereas treatment T3 showed the lowest disease incidence (3.37%), followed by treatment T6 (8.50%), as shown in Table 4. At 55 DAS, the highest (22.01%) disease incidence was recorded from treatment T1 (control), whereas treatment T3 showed the lowest disease incidence (8.30%). At 70 DAS, the highest (26.70%) disease incidence was recorded from treatment T1 (control), whereas treatment T3 showed the lowest disease incidence (9.54%). At 85 DAS, the final disease incidence was recorded, whereas treatment T3 showed the lowest disease incidence (15.23%) and T1 showed the highest (31.25%) (Table 4). Among the treatments, T3 (*Trichoderma harzianum*) suppressed the maximum amount of disease compared to other treatments. From the present study, disease incidence was minimum in treated plants compared to control plants. Fungicide-treated plants always showed better performance in reducing the disease incidence. Among the treatments, T3 (*Trichoderma harzianum*) suppressed the maximum amount of disease compared to other treatments. Sowing dates were also an important factor in controlling the disease incidence. Early or late sowing dates can escape maximum disease infection. Lycomax was the most effective treatment for (Karim et al., 2024b). Hannan *et al.* (2012) reported that combined use of cow cowdung, BINA-biofertilizer, and BAU-biofungicide showed a profound effect in reducing root rot disease and in increasing plant growth parameters of lentil by using these biocontrol agents under field conditions. The present study's findings were consistent with those of Lacicowa and Pieta (1994). They observed that *Trichoderma* spp. was given the best disease control as compared with chemical control.

Table 4. Effect of treatments on disease incidence (%), numbers of pods/plant, numbers of nodule/plant in lentil plant at different dates of data collection.

Treatments	Disease incidence (%)				Numbers of pods/plant		Numbers of nodules/plant	
	40 DAS	55 DAS	70 DAS	85 DAS	70 DAS	85 DAS	70 DAS	85 DAS
T1	20.07 a	22.01 a	26.70 a	31.25 a	37.00 e	43.66 f	0.33 c	0.66 d
T2	17.14 b	19.75 b	23.67 b	27.14 b	41.66 de	47.66 e	1.00 bc	1.33 cd
T3	6.37 g	8.30 g	9.54 g	15.23 g	84.66 a	90.00 a	2.33 a	3.33 a
T4	10.43 e	13.53 e	15.27 e	19.84 e	54.00 c	63.33 c	1.33 abc	2.00 bc
T5	13.76 d	15.50 d	18.51 d	22.65 d	51.00 c	57.33 d	1.00 bc	1.66 bcd
T6	8.50 f	11.12 f	13.10 f	18.18 f	66.66 b	74.00 b	1.66 ab	2.66 ab
T7	15.36 c	17.48 c	20.49 c	24.41 c	47 cd	53.66 d	0.66 bc	1.33 cd
%CV	3.83	2.79	3	2.17	7.86	3.51	52.38	31.09

Means having same letter within a column do not differ significantly at 5% level of probability.

3.4 Effect of treatments on number of pods per plant

Pod number was recorded at 70 and 85 DAS and presented in Table 4. It was observed that pod numbers differ significantly at all the dates of data collection. The maximum pod number was recorded in T3 (84.66) at 40 DAS, which was followed by T6, T4, and T5 having 66.66, 54.00, and 51.00 pod numbers, respectively (Table 4). The minimum 37.00 pod number was recorded in T1, which was similar to T2. At 85 DAS, the highest number of pods was recorded from treatment T3 (90), followed by T6, T4, and T5, and the lowest number of pods was recorded from T1 (43.66). So, the T3 treatment showed a comparatively better result among the seven treatments that were used in this experiment. From the present study, the maximum number of pods was observed at the treated plant compared to the non-treated control plant. Among seven treatments, T3 showed better performance, which was bio-fungicide. Prabu *et al.* (2014) observed that the number, length, fresh weight, and dry weight of the pods of cowpea were higher when treated with spent mushroom substrate (SMS). The present finding was also supported by Shahiduzzaman (2015), who observed that seed treatment with all of the tested fungicides and botanicals reduced the disease severity and increased lentil pod number and crop yield compared to untreated control. Pratibha *et al.* (2016) reported that a significant response to the application of *Trichoderma harzianum* (Th3) was observed on plant growth-promoting parameters at the field level to increase the number of pods per plant.

3.5 Effect of treatments on number of nodules per plant

The number of nodules was counted by visual observation. The number of nodules was recorded at 70 DAS and 85 DAS. At 70 DAS, the maximum number of nodules was recorded from treatment T3 (2.33), which was followed by T6, T4, and T5 having 1.66, 1.33, and 1.00 nodule numbers, respectively, and the minimum number of nodules was recorded from treatment T1 (0.33), which was similar to T2, T4, T5, and T7 (Table 4). At 85 DAS, the maximum number of nodules was recorded from treatment T3 (3.33), and the minimum number of nodules was recorded from T1 (0.66), which was similar to T2, T5, and T7 (Table 4). Among those treatments, Lycomax showed a comparatively better result in increasing the nodule number. Nodule number was recorded at 70 DAS and 85 DAS of sowing, and the average number of nodules was calculated and presented in Fig. 2.

According to the present study, the number of nodules per plant varied among treatments throughout the experimental period. The maximum number of nodules was observed at the treated plant compared to the non-treated control plant. Among seven treatments, T3 showed better performance, which was the bio-fungicide Lycomax. Results of the present study, also supported by Ahmed *et al*. (2021), carried out an experiment to determine the effect of biofertilizer and IPM biopesticide for controlling foot and root rot disease of lentil. Both are found to significantly increase the fresh weight and the number of nodules per plant. Aktar *et al*. (2019) observed that the highest number of nodules of lentil were shown due to the application of cow dung or poultry manure along with or without inorganic fertilizers over the control treatment. Hwang *et al*. (1994) found that severe root rot drastically reduces the number of roots available for symbiotic nodulation, so nodulation decreases as *Fusarium* root rot severity increases, and reduced nodulation can slow plant development and reduce seed yield because of limited nitrogen fixation. Ansari *et al*. (1990) found that soaking the seeds for 12 hours in a 0.3% aqueous pyridoxine solution significantly increased the nodule number, and nitrogenous activity was also noticed.

3.6 Effect of treatments on root length per plant

Root length was recorded at 70 DAS and 85 DAS and presented in Table 5. From the Table, it was observed that root length varied significantly at all the dates of data collection. Maximum root length was recorded in T3 (7.66 cm) at 70 DAS, which was followed by T6, T4, and T5 having 7.33 cm, 66.33 cm, and 6.00 cm root length, respectively (Table 5). The minimum 4.66 cm number was recorded in T1, which was similar to T2. At 85 DAS, the maximum root length was recorded from treatment T3 (10.66 cm), and the minimum root length was recorded from T1 (5.33 cm) (Table 5). Compared to the other treatments, T3 showed a better result in increasing the root length. Root length is an essential trait of lentils, and it has a positive correlation with yield. Root length was influenced by the various *Trichoderma* isolates in the experiment, and root length ranged from 10.43 cm to 13.10 cm (Rai, 2019).

3.7 Effect of treatments on Number of root branch/plant

At 70 DAS, the highest number of root branches was recorded from treatment T3 (11.00), and the lowest number of root branches was

Table 5. Effect of treatments on numbers of pod/plant, number of root branch/plant, total yield/plot (g), total numbers of plant/plot of lentil at different dates of data collection.

Treatments	Root length/plant (cm)		Number of root branch/plant		Total yield/plot (g)	Total numbers of plant/plot
	70 DAS	85 DAS	70 DAS	85 DAS		
T1	4.66 d	5.33 e	5 f	5.33 f	100 g	129.00 e
T2	5.33 cd	6.33 d	6.66 ef	7.00 e	120 f	130.33 e
T3	7.66 a	10.66 a	11.00 a	12.66 a	240 a	155.67 a
T4	6.33 b	9.00 bc	9.66 bc	10.33 c	190 c	142.33 c
T5	6.00 bc	8.33 c	8.66 cd	8.66 d	170 d	136.67 d
T6	7.33 a	9.66 b	10.33 ab	11.33 b	220 b	147.67 b
T7	5.66 bc	7.00 d	7.66 de	7.66 e	140 e	131.67 e
%CV	9.06	4.83	8.33	6.18	1.77	1.64

Means having same letter within a column do not differ significantly at 5% level of probability.

recorded from T1 (5.00) (Table 5). At 85 DAS, the highest number of root branches was recorded from treatment T3 (12.66), and the lowest number of root branches was recorded from T1 (5.33) (Table 5). So, T3 treatment was more effective at increasing the root branch of lentil. In the present study, maximum root length and root branch also varied across treatments. Treated plants showed better performance compared to non-treated control plants. Increasing root length and branches may be contributing to the yield; increasing root growth may contribute to the rapid growth of the plant, increasing the number of branches and the yield. Williams *et al*. (2001) reported that spent mushroom substrate promotes faster crop growth establishment, improved crop density and yield, and increased rooting. The present study's findings, also supported by Hoque *et al*. (2015) and Mia *et al., (*2025), carried out an investigation to evaluate the six selected isolates of three biocontrol agents against foot and root rot pathogens. All of the biocontrol agents showed significantly better germination than the control, resulting in a significant increase in shoot and root length that gave a high vigor index.

3.8 Effect of treatments on yield/plot (g)

The effect of different treatments on yield/plot (g) was found to differ significantly to some extent. The maximum yield (240 g) was recorded in the T3 treatment, where T1 showed statistically that the minimum yield (100 g) was recorded in the control treatment (Table 5). According to the present study, increased yield was recorded in the bio-fungicidal-treated plot compared to the untreated control plot. Bio-fungicidal (Lycomax)-treated plots performed better yields due to the reduction of foot and root rot of lentil. The application of *Trichoderma* strains or products to lentil plants affected the yield in field and greenhouse conditions and when seeds are coated with *Trichoderma*. (Marra *et al*., 2021; Yesmin *et al.,* 2023).

3.9 Effect of treatments on total numbers of plant per plot

Total numbers of plants per plot were significantly different among the different treatments. T3 had the maximum total number of plants per plot (155.67), which was near to T6 (147.67) (Table 5). In the case of plants per plot, number of pods per plant, and yield per plot, similar findings are observed by Khalequzzaman (2016) and Nikson et al. (2024).

3.10 Regression coefficient between disease incidence (%) and plant height (cm) of lentil

The linear regression analysis found a negative relationship between plant height and percent disease incidence. However, plant height response to the intensity of the percent disease incidence can be determined by the regression equation Y = -0.365x + 31.14 (R^2 = 0.9619) (Fig. 2). The fitted line plot showed the regression results graphically with the equation between the dependent variable of plant height and the independent variable of percent disease incidence. The equation indicates that plant height decreases at the rate of -0.365 (number) with an increase of one unit of percent disease incidence. The R^2 value of 0.9619 indicates that plant height can be explained as 96% by the respective function.

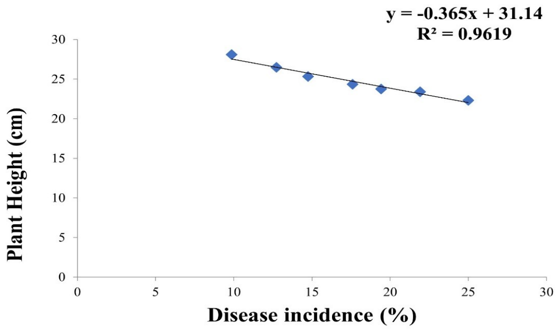

Fig. 2. Regression co-efficient between percent disease incidence and plant height.

3.11 Regression coefficient between disease incidence (%) and pod number of lentil

The linear regression analysis revealed a negative relationship between pod number and percentage disease incidence. However, pod number responds to the intensity of the percent disease incidence, which can be determined by the regression equation Y = -3.3835x + 120.88 (R^2 = 0.8052) (Fig. 3). The fitted plot line

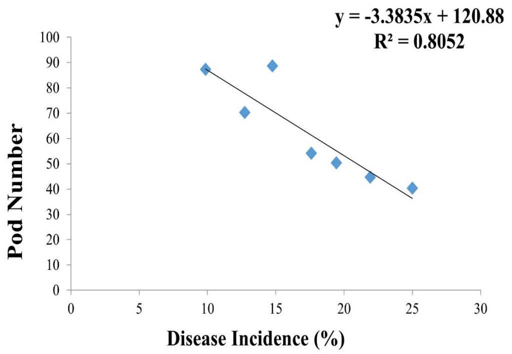

Fig. 3. Regression co-efficient between percent disease incidence and pod number.

graphically showed the regression results with an equation between the dependent variable, pod number, and the independent variable, percent disease incidence. The equation indicates that pod number decreases at the rate of -3.3835 (number) with an increase of one unit of percent disease incidence. The R^2 value of 0.8052 indicates that pod number can be explained as 80% by the respective function.

3.12 Regression coefficient between disease incidence (%) and root branch of lentil

The linear regression analysis found a negative relationship between root branch and percent disease incidence. However, root branch response to the intensity of the percent disease incidence, which can be determined by the regression equation Y = -0.443x + 16.385 (R^2 = 0.996) (Fig. 4). The line of the fitted plot showed the regression results graphically with an equation between the dependent variable of root branch and the independent variable of percent disease incidence. The equation indicates that root branch decreased at the rate of -0.443 (number) with an increase of one unit of percent disease incidence. The R^2 value of 0.996 indicates that the root branch can be explained as 99% by the respective function.

3.13 Regression coefficient between disease incidence (%) and total yield

The linear regression analysis revealed a negative correlation between total yield and % disease incidence. The regression equation Y = -9.7254x + 337.08 (R^2 = 0.988) predicts the overall yield response to the degree of disease incidence (Fig. 5). The fitted line plot graphically represented the regression results, with an equation between the dependent variable, total yield, and the independent variable, % disease incidence. The equation shows that total yield drops at a rate of -9.7254 (number) for every one unit rise in percent disease incidence. With an R^2 value of 0.988, the function explains 98% of total yield.

A basic economic analysis was performed to assess the cost-benefit ratio of different treatments. The Lycomax (T3) treatment resulted in a yield of 240 g per 2 m^2 plot, compared to 100 g in the untreated control. Assuming a market price of 100 BDT/kg, this corresponds to a gross return of 24 BDT from T3 versus 10 BDT from the control. The estimated cost of Lycomax per plot (including seed treatment and spraying) was approximately 2.5 BDT, resulting in a net gain of over 11.5 BDT per plot. This indicates that Lycomax is not only effective for disease suppression and yield enhancement but also economically viable for practical lentil cultivation.

4. CONCLUSION

The treatments demonstrated significant impacts on the lentils total plant number, plant height,number of branches per plant, root length, number of root branches per plant, number of root nodules, number of root branches/plant, total yield per plot (g), total number of plants per plot, and flowering and

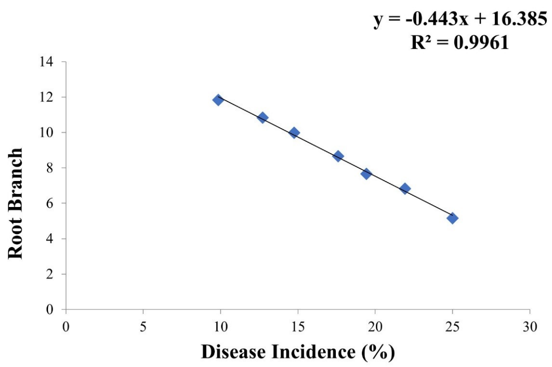

Fig. 4. Regression co-efficient between percent disease incidence and root branch.

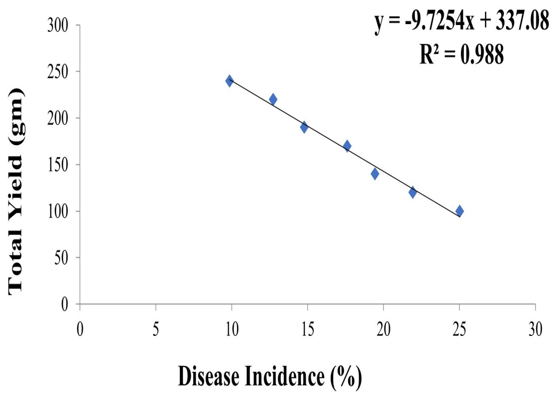

Fig. 5. Regression co-efficient between percent disease incidence and total yield.

fruiting. The results of this study demonstrated that applying a biofungicide (Lycomax) to the plant had a direct impact on reducing the incidence of lentil foot and root rot disease, improving other growth parameters, and developing a healthy appearance. Although other treatments, such as Dynamic, *Tricost*, *Trichoderma* WP, and *Decoprime*, demonstrated superior performance in reducing lentil foot and root infection, they were not as effective as the control.

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