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BIOLOGICAL CONTROL OF FOOT AND ROOT ROT DISEASE OF PEA (*PISUM SATIVUM* L.) BY USING A FORMULATED PRODUCT OF *TRICHODERMA*

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Abstract: Foot and root rot is one of the most serious yield-reducing diseases in peas. *Fusarium oxysporum* and *Sclerotium rolfsii* are primarily responsible for the development of pea foot and root rot diseases. This study was conducted to test the fungicide of the *Trichoderma* group for the control of foot and root rot in peas. Bio-fungicidal treatments of the *Trichoderma* group – Decoprima (T2), Lycomax (T3), Dynamic (T4), Tricost (T5), Provax 200 (T6), and *Trichoderma* (T7)– were used to compare results with untreated control plots. Lycomax (T3) performed well in suppressing pea foot and root rot disease, as well as other growth traits across different days after sowing (DAS). Lycomax (T3) gave the highest yield (39.81 g/plot) at 92 DAS compared to other treatments and untreated plots (11.67 g/plot). Although the chemical treatment Provax 200 (T6) controlled pea foot and root rot disease and yielded 33.76 g/plot, it is not eco-friendly. Lycomax (T3) achieved the greatest results at 75 DAS in all traits, including surviving seedlings (64.67/plot), infected plants (4/plot), plant height (67.33 cm/plot), and root branches per plant (33.33/plot). The plot treated with Lycomax (T3) had the greatest root length (28.33 cm/plot), root nodules (30.33/plant/plot), and branches (33.33/plant/plot) at 82 days after sowing. The flowers (76/plot) and pods (12.33/plot) peaked at 65 and 75 DAS, respectively. The current study has demonstrated that Lycomax (generic name: *Trichoderma)* is the best bio-fungicide to treat pea foot and root rot disease in an eco-friendly manner and boost production by improving plant health.

Key words: bio-fungicide, foot and root rot, *Fusarium*, pea, *Trichoderma*.

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Introduction

Legumes encompass peas, which produce pods containing seeds or beans. The peas that are commonly consumed include green, snow, and snap varieties. Garden peas typically have rounded, green pods with sweet and starchy peas inside. Peas belong to the Fabaceae family, also known as the bean or pulse family. This family, Leguminosae (Fabaceae), consists not only of peas such as *Pisum sativum* L., but also of nearly 18,000 other species. Additionally, it includes species such as *Lathyrus* (160), *Lens* (4), and *Vicia* (160–250).

Although peas originate from Asia and the Middle East, they are cultivated worldwide. This ancient crop, whose exact origins are uncertain but are believed to date back to around 1800 BC according to Rana et al. (2021), was initially discovered in regions around the Mediterranean, East Africa, Ethiopia, and Central Asia.

However, human intervention has led to its widespread cultivation in numerous temperate countries such as the Netherlands, France, the UK, the USA, Australia, and New Zealand. Pea cultivation has historical roots in Europe, dating back to the stone and bronze periods, while in India it has been cultivated since around 200 BC, and in New Zealand since 1900. Approximately 7000 years ago, peas were commonly intercropped with barley and wheat (McPhee, 2003).

Iqbal et al. (2019) observed notable disparities in the proximate composition, mineral content, and amino acid profile among lentils, chickpeas, cowpeas, and green peas. Peas are rich in vitamins, minerals, antioxidants, and phytonutrients that contribute to eye health and potentially mitigate certain malignancies. Specifically, peas contain lutein and zeaxanthin, which safeguard against cataracts and age-related macular degeneration (AMD) by blocking harmful blue light. Additionally, peas provide essential nutrients such as magnesium and potassium, which contribute to lowering blood pressure.

Despite their nutritional significance, peas are vulnerable to various diseases and infections caused by biological agents or climatic factors. Peas are known as a self-intolerant crop (Schreuder, 1949). The worst illness of *Pisum sativum* is foot and root rot among the destructive diseases. This condition is typically induced by a range of microorganisms, including bacteria, viruses, oomycetes, and fungi. Furthermore, root nematodes and other parasites exacerbate the plant damage, creating opportunities for fungal pathogens to proliferate.

Fungi predominantly contribute to foot and root rot disease in peas, with species such as *Fusarium solani* being particularly destructive. *Fusarium solani*, often associated with *Aphanomyces euteiches* Drechs, poses a significant threat to *Pisum sativum*, leading to stunted root systems and substantial crop losses. Common symptoms of foot and root rot include root tip browning, lesions, decay, leaf yellowing, wilting, and reduced crop yield.

Numerous research efforts have aimed to combat pea foot and root rot, albeit with limited success or potential hazards to health and the environment. Utilizing bio-fungicides such as *Trichoderma spp.* represents a promising approach due to their adaptability, rapid growth, and broad antibiotic spectrum. *Trichoderma spp.* effectively control soil-borne pathogens such as *Fusarium, Pythium, Phytophthora,* and *Rhizoctonia solani*, thereby promoting sustainable agriculture. These bio-fungicides not only reduce disease severity, but also enhance plant defence mechanisms and competitiveness against pathogens through the production of secondary metabolites such as chitinase, proteases, and β-1,3-glucanase. This research focused specifically on the use of fungicides of the *Trichoderma* group to develop an efficient and environmentally friendly strategy to control foot and root rot in peas.

Material and Methods

Planting material and experimental design

The investigation was conducted at the Plant Pathology Research Field of Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur-5200, Bangladesh. The experimental field was composed of medium high granular loam soil. According to SRDI (Soil Resource Development Institute, Dinajpur), the pH of the soil was 5.2. Pea seeds sourced from a local supplier in Dinajpur were used for the experiment. A Randomized Complete Block Design (RCBD) with three replications was implemented, dividing the field into three blocks, each containing seven plots of 2 m x 1 m. The plots were arranged with a row spacing of 30 cm and a plant spacing of 6 cm, with 1 m between blocks and 0.5 m between plots. Seeds were sown at a depth of 3 cm. Seven treatments: T_2 = seed treatment with Decoprima and spraying at the basal region of the plants, T_3 = seed treatment with Lycomax and spraying at the basal region of the plants, T_4 = seed treatment with Dynamic and spraying at the basal region of the plants, T_5 = seed treatment with Tricost and spraying at the basal region of the plants, T_6 = seed treatment with Provax and spraying at the basal region of the plants, T_7 = seed treatment with *Trichoderma* and spraying at the basal region of the plants were evaluated with T_1 = control (without any treatment).

Soil preparation and fertilization

A well-drained area was selected and prepared meticulously for pea cultivation. The land was plowed, cross-plowed, and cleansed, and then harrowed and levelled to achieve the desired soil texture. According to BARI recommendations, manures and fertilizers were applied, including urea (250g/ha), TSP (400g/ha), potash (200g/ha), boron (20g/ha), and zinc (20g/ha). Healthy, disease-free seedlings were chosen for sowing, and 250g of pea seeds were distributed per experimental allotment in rows. Sowing took place on 3 December 2021, with a row spacing of 30 cm and a sowing depth of 1–2 cm. During intercultural operations, germination commenced nine days after sowing, and two rounds of thinning were conducted at 15 and 30 days after sowing (DAS) to maintain an optimal plant population. Two irrigation treatments were applied, with the first irrigation at 30 DAS and the second after weeding, spaced 15 days apart. Weeding was performed twice, first at 30 DAS and then at 60 DAS, using a spade and a trowel. The bio-fungicidal solution was prepared by dissolving a specific quantity of bio-fungicide in the required amount of water. This solution was applied three times throughout the experiment. The spraying was carried out every fifteen days using a hand sprayer. The fungicidal solution was sprayed with appropriate care to ensure adequate coverage of the basal region of the plant. Before the spray tank was filled with the fungicide, it was thoroughly cleaned. Five bio-fungicides, one fungicide, and one control were selected as treatments for managing foot and root rot disease.

Table 1. Information of the bio-fungicides and fungicides.

Common name	Recommended dose	Formulation	Amount of fungicide/liter of water
Decoprima	*Trichoderma* sp. 4.35x 10^5 cfu/g *Streptomyces* sp. 1.16 x 10^6 cfu/g *Geobacillus* sp. 1.94 x 10^6 cfu/g	Powder	0.14 g
Lycomax	*Trichoderma harzianum* 2–3% *Trichoderma viridae* 0.5–1% *Metarhizium anisopliac* 2–3% *Beauveria bassiana* 2–3%	Powder	0.75 g
Dynamic wettable powders (WP)	*Bacillus amyloliquefaciens* 1x10^6 cfu/g	Powder	0.5 g
Tricost 1% WP	*Trichoderma* 2 x106 cfu/g	Powder	1 g
Provax 200 WP	Carboxin 37.50% + Thiram 37.50%	Powder	0.75 g
Trichoderma	*Trichoderma*	Powder	1 g

Data collection

Data on plant growth characteristics and diseases were gathered four times. The collection of data began at 45 DAS and proceeded every 10 days. The plots of pea were purposefully visited to measure the data of various agronomic parameters and to examine and record the data on foot and root rot diseases. After documenting infected plants, the dead plants were removed from the plot. Data was collected on some tested plant traits and disease incidence at different days after sowing (DAS).

Plants affected by *Fusarium* and *Sclerotium* show stunting, wilting, withering, chlorosis, necrosis, and defoliation of plant parts, which consequently results in the death of the whole plant. By observing the visual symptoms of foot and root rot, the number of defective or infected plants per plot was determined and recorded at various phases of plant growth. Approximately ten plants were randomly collected from each plot. Initial data collection began at 45 DAS and continued at 10-day intervals. In addition, the total number of infected plants per plot was counted. The incidence of disease was expressed as a percentage. The percent of disease incidence was calculated using the formula provided by Agrios (2005).

$$\text{Disease incidence (\%)} = \frac{\text{Number of infected plants}}{\text{Total number of inspected plants}} \times 100 \quad (1)$$

After evaluating the disease incidence in the experimental field, the plant samples showing the symptoms of foot and root rot were wrapped in paper bags and delivered to the Plant Pathology Laboratory of Hajee Mohammad Danesh Science and Technology University for isolation and confirmation of the fungal pathogens, namely *Fusarium oxysporum* and *Sclerotium rolfsii*.

Using a meter scale, the plant height was measured in centimeters at both the vegetative and reproductive development stages. For measuring plant height, 10 plants were randomly selected from each plot and data were recorded at 45, 55, 65, and 75 days after sowing (DAS). The number of branches on 10 plants from each plot was counted by randomly selecting 10 plants from each plot. Data were recorded at 45, 55, 65, and 75 DAS. At 77 and 82 DAS, the root length of 10 randomly selected plants from the interior rows of each plot was measured. At 77 and 82 DAS, the number of root branches was counted on 10 randomly selected plants from the interior rows of each plot. Ten plants were randomly selected from the interior rows of each plot in order to determine the number of root nodules. At 77 and 82 DAS, the total number of root nodules of the chosen plants was recorded. At 65 DAS, the number of flowers on 10 randomly selected plants was counted and recorded. As in the past, the plants were selected and the number of pods recorded at 75 DAS. When 80 to 90 percent of the plants had reached full maturity, the harvest was taken. Several indicators, such as pod color, pod filling, plant water content, etc., were used to determine the stage of maturation. Two harvests were conducted depending on maturity. Each time the seeds were harvested, they were hand-picked and packaged with appropriate identifiers based on the plot and treatment. After each collection, the weight of the pods and then the seeds were recorded immediately. The total output was calculated by adding the harvest from both times. Therefore, the total yield was recorded at 92 DAS. The total yield was measured in grams (g) for data preparation purposes.

Statistical analysis

A computer program, Statistix-10, conducted an accurate statistical analysis. The means of the interventions were compared using the LSD (Least Significant Difference) with an α value of 0.05% (Gomez and Gomez, 1984).

Results and Discussion

An attempt was made to observe the efficacy of the treatments on different parameters of the pea plants by collecting and comparing data of different dates of data collection.

Efficacy of the treatments

Fungal species, namely *Fusarium oxysporum* and *Sclerotium rolfsii*, were observed as pathogens of pea plants. The foot and root rot disease of *Vicia faba* can be caused by a number of different species of fungal pathogens, namely, *Fusarium*, *Rhizoctonia*, *Pythium*, and *Phoma* (Rubiales and Khazaei, 2022). At 45 DAS, the maximum number of survived plants was recorded at T_3 (86), followed by T_1, T_2, and T6. On the contrary, the minimum number of plants was recorded at T_4 (64), followed by T_5 and T_7 with 65 and 68.33 plants, respectively. At 55 DAS, the number of survived plants was highest at T_3 (86), followed by T_1 with 72 plants. The maximum number of survived plants at 65 DAS was at T_6 (72), followed by T_3 (71.67). The lowest number of survived plants was recorded at T_1 (55), followed by T_2 with 56.67 plants. At 75 DAS, the highest number of plants was recorded at T_6 (69.33), followed by T_2 and T_3 with 59.33 and 64.67 plants, respectively. In contrast, the lowest number of plants was recorded at T_1 (50), followed by T_7 with 53.33 plants (Table 2).

Table 2. Efficacy of treatments on survived seedlings or total plant population, and total number of infected plants per plot at different days after sowing (DAS).

Treatment	Number of survived seedlings				Number of infected plants			
	45 DAS	55 DAS	65 DAS	75 DAS	45 DAS	55 DAS	65 DAS	75 DAS
T1 = Control	72.00abc	72.00abc	55.00b	50.33c	5.00a	5.33bc	9.33a	11.00ab
T2 = Decoprima	74.00abc	74.00abc	56.67b	59.33abc	1.33bc	9.67a	7.33ab	12.67a
T3 = Lycomax	86.00a	86.00a	71.67a	64.67ab	0.00c	1.33c	2.00b	4.00c
T4 = Dynamic	64.00c	64.00c	60.33b	61.67abc	1.67bc	8.33ab	9.00a	10.33abc
T5 = Tricost	65.00bc	65.00bc	57.00b	59.00abc	2.00b	9.33ab	11.00a	12.33a
T6 = Provax	80.33ab	80.33ab	72.00a	69.33a	1.00bc	2.67c	2.33b	5.67bc
T7 = Trichoderma	68.33bc	68.33bc	55.33b	53.33bc	0.67bc	8.33ab	9.00a	11.00ab
%CV	7.86	3.51	2.17	3.44	31.09	3.82	3.83	2.17

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

After 45 DAS, some plants were found to be infected with various symptoms. At 45 DAS, the highest number of infected plants was at T_1 (5) and the lowest number of infected plants was at T_3 (0), followed by T_7 (0.67). At 55 DAS, the highest number of infected plants was recorded at T_2 (9.67), followed by T_4 with 8.33 plants. At 65 DAS, the highest number of infected plants was recorded at T_5 (11), followed by T_1 and T_2, with 9.33 and 7.33 plants, respectively. At 75 DAS, the highest number of infected plants was recorded at T_2 (12.67), followed by T_1 with 11 plants (Table 2). Different species of *Trichoderma* are used as biological control agents and as an alternative to chemical fungicides to control a variety of plant diseases (Hu et al., 2022).

The variation in the height of pea plants was observed due to application of different treatments (Table 3). At 45 DAS, plants reached the greatest height at T_6 (24.00 cm), whereas the height was the lowest at T_5 (13.00 cm). At 55 DAS, plants reached the highest height at T_3 (33.67 cm), followed by T_1 and T_6 with a plant height of 28 and 31.67 cm. The plants had the lowest height at T_2 (21 cm), followed by T_4 (23.33 cm). At 65 DAS, the plants were observed to have reached the highest height at T_3 (67.33 cm), followed by T_1 (58.67 cm) and T_2 (57.33 cm). At 75 DAS, the plants were observed to have reached the maximum height at T_3 (67.33 cm), followed by T_6 (65 cm). The plants with the lowest height were found at T_4 (47 cm), followed by T_1 (54.33 cm) and T_2 (51 cm). Although plant height increases with increasing plant age, variation was observed due to the implementation of several treatments. Maximum plant height was noted in the treated plots compared to the control plots. Plants treated with Lycomax (T3) reached the maximum height compared to other treatments at different dates of data collection.

Table 3. Efficacy of treatments on plant height and number of branches at different days after sowing (DAS).

Treatments	Plant height (cm)				Number of branches			
	45 DAS	55 DAS	65 DAS	75 DAS	45 DAS	55 DAS	65 DAS	75 DAS
T1 = Control	16.67ab	28.00abc	58.67ab	54.33b	9.00b	13.00abc	14.67b	20.67bc
T2 = Decoprima	18.67ab	21.00c	57.33ab	51.00b	6.67b	10.67bc	16.33b	19.00bc
T3 = Lycomax	20.67ab	33.67a	67.33a	67.33a	12.33a	17.67a	25.00a	33.33a
T4 = Dynamic	15.67b	23.33c	51.00b	47.00b	9.00b	11.00bc	16.00b	22.67b
T5 = Tricost	13.00b	23.33c	53.67ab	49.33b	8.67b	5.33d	10.33c	16.67c
T6 = Provax	24.00a	31.67ab	46.67b	65.00a	14.00a	14.00ab	22.00a	30.67a
T7 = Trichoderma	15.00b	24.67bc	48.33b	51.33b	8.67b	8.67cd	13.00bc	23.00b
%CV	2.17	2.44	7.86	6.42	3.82	2.22	2.42	3.83

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

The treatments applied had a great impact on the number of branches of the pea plants (Table 3). At 45 DAS, the highest number of branches was observed at T_6 (14), followed by T_3 (12.33). At 55 DAS, the plants obtained the highest number of branches at T_3 (17.67), followed by T_1 (13) and T_6 (14). At 65 DAS, the plants reached the maximum number of branches, recorded at T_3 (25), followed by T_6 (22). At 75 DAS, plants reached the highest number of branches at T_3 (33.33), followed by T_6 (30.67). It was observed that plants treated with bio-fungicides produced more branches than untreated plants. Among the treated bio-fungicides, Lycomax (T3) again showed the most effective performance in producing more branches in pea plants. Lycomax can reduce 9.09% of plant infection and 89.04% of leaf infection (Mollah and Hassan, 2023).

The plants with the highest number of flowers at T_3 (76) were followed by the plants treated with T_1 and T_6. The number of flowers was 50 and 69.67, respectively (Table 4).

The first fruiting was recorded at 75 DAS (Table 6). The highest number of pods was recorded at T_3 (12.33), followed by T_6 (11.67).

The lowest number of pods was recorded at T_1 (2.67), followed by T_2 (4.67), T_4 (4), and T_5 (3.65).

Table 4. Efficacy of treatments on flowering of plants (at 65 DAS), number of pods/plant (at 75 DAS), root length of plants/plot (at 77 and 82 DAS), and number of root branches of plants/plot (at 77 and 82 DAS).

Treatment	No. of flowers	No. of pods	Root length (cm)		No. of root branches	
	65 DAS	75 DAS	77 DAS	82 DAS	77 DAS	82 DAS
T1 = Control	50.00bc	2.67b	11.67bcd	20.00b	24.00c	20.00b
T2 = Decoprima	45.67c	4.67b	9.67cd	18.33bc	18.67e	22.33b
T3 = Lycomax	76.00a	12.33a	18.33a	28.33a	31.67a	33.33a
T4 = Dynamic	46.00c	4.00b	13.00bc	19.33b	23.67c	19.33b
T5 = Tricost	48.67c	3.67b	8.00d	13.33c	17.67e	16.33b
T6 = Provax	69.67ab	11.67a	15.67ab	27.33a	29.33b	33.67a
T7 = *Trichoderma*	49.33c	5.00b	10.67cd	20.67b	21.67d	20.33b
%CV	7.86	31.07	3.42	3.82	2.12	3.84

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

The root length of plants/plot was recorded at 77 and 82 DAS (Table 6). The impact of the applied treatments on the root length of the pea plants was significant in the study. At 77 DAS, the largest root length was recorded at T_3 (18.33 cm), followed by T_1 (11.67 cm) and T_4 (13). A small root length was observed at T_5 (8 cm), followed by T_2 (9.67 cm) and T_5 (8 cm). At 82 DAS, the plants had the highest root length at T_3 (28 cm), followed by T_1, T_4, T_6 and T_7 (Table 4). All the bio-control agents resulted in significantly better germination than the control treatment and a significant rise in root and shoot length, leading to a high vigor index (Hoque et al., 2014). Plant height, branches, root length and number of root nodules increased with increasing age of the pea plants. *Trichoderma* species promote plant defense mechanisms and improve the growth of plant and root (Sharma et al., 2022).

The number of root branches/plant/plot was recorded at 77 and 82 DAS (Table 4). At 77 DAS, the number of plants with the maximum number of branches was highest at T_3 (31.67), followed by T_1 (24), and T_4 (23.67). At 82 DAS, the number of plants, with the lowest number of branches was at T_5 (16.33), followed by T_1, and T_2 (Table 4). Long bushy roots play a significant role in the final yield.

The average number of root nodules (plants/plot) was recorded at 77 and 82 DAS (Table 5). At 77 DAS, the maximum number of root nodules was noted at T_3 (23), followed by T_6 (22.33). The minimum number of root nodules was observed at T_1 (9.33), followed by T_2. At 82 DAS, the highest number of root nodules was noticed at T_3 (30.33), followed by T_4 (24.33). Root rot drastically reduces the number of roots available for symbiotic nodulation (Hwang et al., 1994). Thus, nodulation reduces as *Fusarium* root rot severity rises and contracted nodulation can slow plant growth. In addition, a 1% talc-based formulation of *T. harzianum* resulted in higher germination and improved plant height, root length and yield (Sinha et al., 2018).

Table 5. Efficacy of treatments on root nodules/plant/plot (at 77 and 82 DAS), pod weight/plant/plot (at 85 and 92 DAS), seed weight/plant/plot after harvest (at 85 and 92 DAS).

Treatment	Number of root nodules		Pod weight (g)		Seed weight (g)	
	77 DAS	82 DAS	85 DAS	97 DAS	85 DAS	92 DAS
T1 = Control	9.33c	19.33bc	0.49b	33.50c	0.23b	11.43b
T2 = Decoprima	10.67bc	14.67c	0.48b	28.31c	0.21b	14.86b
T3 = Lycomax	23.00a	30.33a	0.77a	76.46a	0.34a	39.47a
T4 = Dynamic	12.33bc	24.33ab	0.52b	33.64c	0.23b	13.14b
T5 = Tricost	13.33bc	17.33bc	0.52b	36.79bc	0.21b	19.99b
T6 = Provax	22.33a	27.33a	0.71a	69.05ab	0.31a	33.45a
T7 = *Trichoderma*	14.67b	20.00bc	0.47b	42.72abc	0.20b	18.04b
%CV	2.17	2.42	33.08	6.46	32.02	2.14

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

At 85 DAS, the highest pod weight was at T_3 (0.77 g), followed by T_6 (0.71 g). The lowest pod weight was recorded at T_7 (0.47 g), followed by T_1 with a pod weight of 0.49 g. At 92 DAS, the highest pod weight was obtained at T_3 (76 g), followed by T_6 and T_7 with a pod weight of 69.05 and 42.72 g, respectively (Table 5). The lowest pod weight was obtained at T_2 (28.31 g), followed by T_1, T_4 and T_5

with a pod weight of 33.50, 33.64 and 36.79 g, respectively. A good yield depends on the number of sufficient flowers and pods on the plants. Due to the application of bio-fungicides, the pea plants showed maximum yield. Of all the bio-fungicides used, Lycomax (T_3) performed best, as it produced more flowers and pods than before and thus played a significant role in yield. In the untreated control plot, the yield was lower. *Trichoderma harzianum* (Th3) significantly increases the numbers of pods/plant in the field (Ketta and Hewedy, 2021).

The seed weight of the different plots after harvest was recorded at different dates (85 DAS and 92 DAS) as shown in Table 5. At 85 DAS, the highest seed weight was recorded at T_3 (0.34 g), followed by T_6 (0.31 g). The lowest seed weight was recorded at T_7 (0.20 g), followed by T_1 (0.23).

At 92 DAS, the highest seed weight was recorded at T_3 (39.47 g), followed by T_6 (33.45 g). The lowest seed weight was recorded at T_1 (11.43 g), which was followed by T_2 (14.86 g), and T_4 (13 g). Provax-200 significantly reduces the seedling mortality and improves seed yield in pea (Akhter et al., 2015).

The total harvest (pod and seed weight) was recorded at 92 days after sowing (Table 6). The efficacy of the applied treatments was evaluated based on the total harvest (pod and seed weight). The maximum pod weight was obtained at T_3 (77.23 g), followed by T_6 (69.77 g). The minimum pod weight was recorded at T_2 (28.79 g), followed by T_1 (33.99 g).

Table 6. Total yield (pod and seed weight/plot) and disease incidence (%).

Treatments	Total yield		Disease incidence (%)			
	Pod weight (g)	Seed weight (g)	45 DAS	55 DAS	65 DAS	75 DAS
T1 = Control	33.99c	11.67b	10.31a	8.84ab	14.75a	20.06a
T2 = Decoprima	28.79c	15.07b	2.933bc	9.80 a	11.45ab	18.56a
T3 = Lycomax	77.23a	39.81a	0.00c	1.40c	1.94c	3.99c
T4 = Dynamic	34.16c	13.37b	4.64b	9.26ab	10.74ab	12.68ab
T5 = Tricost	37.13bc	20.20b	5.47b	11.34a	13.25a	16.19a
T6 = Provax	69.77ab	33.76a	4.30b	4.22bc	5.08bc	6.86bc
T7 = *Trichoderma*	43.19bc	18.24b	3.99b	7.94ab	9.93ab	12.77ab
%CV	2.16	6.83	28.64	29.33	3.84	2.69

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

The maximum seed weight was recorded at T_3 (39.81 g), followed by T_6 (33.76 g). If the seeds are treated with fungicides/botanicals, the severity of the disease decreases and the yield of lentil pods and plants increases (Shahiduzzaman, 2015). The minimum seed weight was recorded at T_1 (11.67 g), followed by T_2 with 15.07 g. The maximum number of plants was recorded in bio-fungicide treated plots compared to the control plots. A large number of plants eventually contributed to the yield. Application of *Trichoderma* can improve seedling growth and yield in various cereals and vegetables such as tomato, cucumber, and maize (Hossain and Akhter, 2020). Different species of *Fusarium* are the most dominant species causing root rot in faba bean crops and are responsible for severe yield losses (Yu et al., 2023).

Disease incidence (%) during the plant growth period, at several days after sowing, was recorded on the basis of visible symptoms. Seven treatments were compared for disease incidence observed at 45 DAS, 55 DAS, 65 DAS and 75 DAS. At 45 DAS, the highest disease incidence (10.31%) was recorded at T_1 (control), whereas T_3 had the lowest disease incidence (0%), followed by T_2 (2.933%). The maximum disease incidence (11.34%) was observed at T_5 at 55 DAS, whereas T_3 had the minimum disease incidence (1.4%). The highest disease incidence (14.75%) was recorded at T_1 (control) at 65 DAS, whereas T_3 displayed the minimum disease incidence (1.94%). The final disease incidence was recorded at 75 DAS, with T_3 having the minimum disease incidence (3.99%) and T_1 having the highest (20.06%). Thus, the treatment with Lycomax (T_3) showed the best result in managing disease incidence (Table 6). *Trichoderma harzianum* treated pea seeds showed a disease incidence of 22.14% (Nazir et al., 2022). Among all bio-fungicides, Lycomax (T3) showed the most effective performance in plant protection. The chemical treatment such as Provax 200 also showed effective results in plant protection. By managing foot and root rot disease of pea, bio-fungicide (Lycomax) played the most important role and contributed significantly to the total yield. *Trichoderma* showed a great impact on plant survival in the present study. According to Kashem et al. (2011), the macerated extract of *Fusarium solani* + *Trichoderma harzianum* had the best result in combating root rot of lentil with the maximum seed germination (100%), and number of branches/five plants (15.56). The effectiveness of Trichoderma in disease suppression is attributed to several mechanisms, including hyper-parasitism, antibiosis, induced resistance in the host plant, and competition for nutrients and space (Harman et al., 2004). Studies have shown that *Trichoderma harzianum* exhibits antagonistic activities against various *Fusarium* species, including *Fusarium solani, F. oxysporum, and F. incarnatum*, with inhibition rates ranging from 50.8% to 85% (Hussein et al., 2022). The volatile compounds produced by *T. harzianum* contribute significantly to inhibiting *Fusarium* species. In pea crops, *Trichoderma* and its secondary metabolites play a crucial role in mitigating root rot disease by enhancing protective mechanisms (Ketta and Hewedy, 2021).

Regression coefficient between percent disease incidence and plant height

The linear regression analysis revealed a negative relationship between plant height and percent disease incidence. The response of plant height to the intensity of the percent disease incidence was estimated by the regression equation Y= -

0.875x + 46.07 (R^2 = 0.539). The fitted line plot graphically displayed the regression results with the equation between the dependent variable of plant height and the independent variable of percent disease incidence. The equation stated that plant height declined at a rate of 46.07 with an increase of one unit of percent disease incidence. The R^2 value of 0.539 indicated that 53% of the maximum plant height could be explained by the respective function (Figure 1).

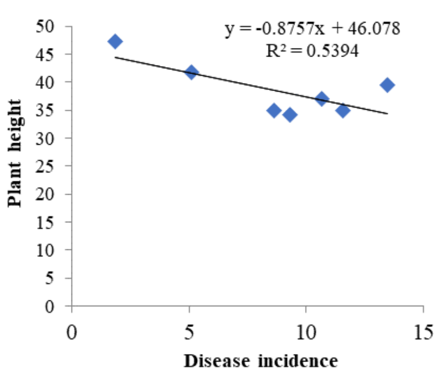

Figure 1. Regression co-efficient between percent disease incidence and plant height.

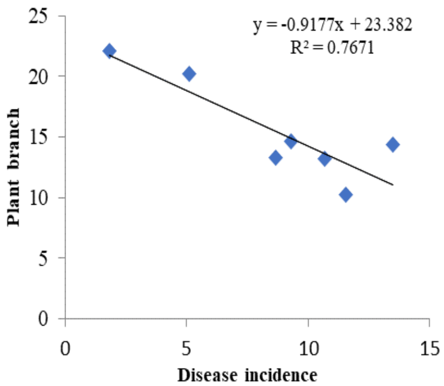

Figure 2. Regression co-efficient between percent disease incidence and branch number.

Regression coefficient between percent disease incidence and the number of plant branches

The linear regression analysis revealed a negative relationship between the number of plant branches and percent disease incidence. The response of the number of plant branches to the intensity of the percent disease incidence was determined by the regression equation Y = -0.917x + 23.38 (R^2 = 0.767). The fitted line plot graphically showed the regression results with the equation between the dependent variable of the number of plant branches and the independent variable of percent disease incidence. The equation indicated that the number of plant branches decreased at a rate of 23.38 (number) with an increase of one unit of percent disease incidence. The R^2 value of 0.767 indicated that 76% of the number of plant branches could be explained by the respective function (Figure 2).

Regression coefficient between percent disease incidence and plant root length

The linear regression analysis shows a negative relationship between root length and percent disease incidence. The response of root length to the intensity of the percent disease incidence was determined by the regression equation Y= -0.470x + 12.44 (R^2 = 0.748). The fitted line plot graphically showed the regression results with the equation between the dependent variable of root length and the independent variable of percent disease incidence. The equation showed that the root length decreased at a rate of 12.44 (number) with an increase of one unit of percent disease incidence. The R^2 value of 0.748 indicated that 74% of the root length could be explained by the respective function (Figure 3).

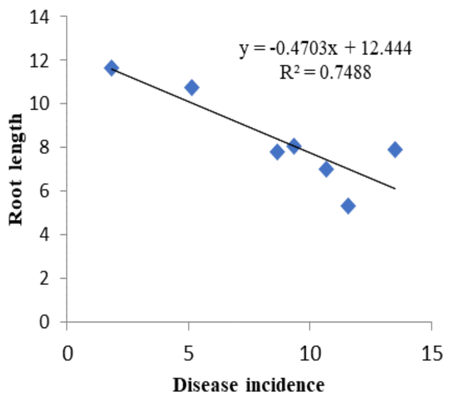

Figure 3. Regression coefficient between percent disease incidence and plant root.

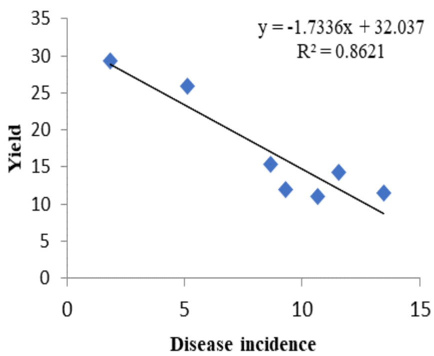

Figure 4. Regression coefficient between percent disease incidence and yield.

Regression coefficient between percent disease incidence and yield

The linear regression analysis revealed a negative relationship between yield and percent disease incidence. The response of yield to the intensity of the percent disease incidence was determined by the regression equation Y = -1.733x + 32.03 (R^2 = 0.862). The fitted line plot graphically represents the regression results with the equation between the dependent variable of total yield and the independent variable of percent disease incidence. The equation showed that the yield decreased at a rate of 32.03 (number) with an increase of one unit of percent disease incidence. The R^2 value of 0.862 indicated that 86% of the yield could be explained by the respective function (Figure 4).

Conclusion

The treatments had definite effects on total plant number, plant height, number of branches, root length, number of root nodules, flowering and fruiting of the pea plants. The number of healthy plants was highest in the plot where the plants were treated with Lycomax. Lycomax-treated plants had more branches, greater height, longer roots, more root nodules and accelerated flowering and fruiting. The only chemical treatment (Provax 200) applied to the plants also showed healthy growth traits, but was found less effective than Lycomax. Poor growth traits of plants were found in the untreated control plot. Lycomax-treated plants were hardly affected by foot and root rot disease. Untreated plants, on the other hand, were mostly infected. Considering the eco-friendly management, Lycomax can be recommended for use in farmers' field for the feasible management of foot and root rot disease of pea and other vegetables.

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BIOLOŠKO SUZBIJENJE BOLESTI TRULEŽI STABLA I KORENA GRAŠKA (*PISUM SATIVUM* L.) KORIŠĆENJEM FORMULISANOG PROIZVODA SA GLJIVAMA IZ RODA *TRICHODERMA*

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R e z i m e

Trulež stabla i korena je jedna od najozbiljnijih bolesti koje smanjuju prinos graška. *Fusarium oxysporum* i *Sclerotium rolfsii* su prvenstveno odgovorni za razvoj bolesti truleži stabla i korena graška. Ova studija je sprovedena kako bi se testirao fungicid na bazi gljivice *Trichoderma* za suzbijanje truleži stabla i korena graška. Bio-fungicidni tretmani na bazi ove gljivice – Decoprima (T2), Lycomax (T3), Dynamic (T4), Tricost (T5), Provax 200 (T6), i *Trichoderma* (T7) – korišćeni su za poređenje rezultata sa netretiranim kontrolnim parcelama. Lycomax (T3) je dao dobre rezultate u suzbijanju bolesti truleži stabla i korena graška, kao i u drugim osobinama rasta tokom različitih dana nakon setve. Lycomax (T3) je dao najviši prinos (39,81 g/parceli) 92 dana nakon setve u poređenju sa drugim tretmanima i netretiranim parcelama (11,67 g/parceli). Iako je hemijski tretman sa bio-fungicidom Provax 200 (T6) kontrolisao trulež stabla i korena graška i dao prinos od 33,76 g/parceli, on nije bezbedan za životnu sredinu. U tretmanu sa bio-fungicidom Lycomax (T3) postignuti su najbolji rezultati 75 dana nakon setve u pogledu svih karakteristika, uključujući preživele sejance (64,67cm/parceli), zaražene biljke (4/parceli), visinu biljke (67,33 cm/parceli) i grane korena po biljci (33,33/parceli). Na parceli koja je tretirana bio-fungicidom Lycomax (T3) postignuta je najveća dužina korena (28,33 cm/parceli), najveći broj nodula na korenu (30,33/biljci/parceli) i najveći broj grana (33,33/biljci/parceli) 82 dana nakon setve. Najviše cvetova (76/parceli) i mahuna (12,33/parceli) je bilo 65 odnosno 75 dana nakon setve. Ova studija je pokazala da je Lycomax (generički naziv: *Trichoderma*) najbolji bio-fungicid za tretiranje bolesti truleži stabla i korena graška i povećanje proizvodnje, a u isto vreme je bezbedan za životnu sredinu.

Ključne reči: bio-fungicid, trulež stabla i korena, *Fusarium*, grašak, *Trichoderma*.

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