ASIAN JOURNAL OF AGRICULTURE
Volume 6, Number 1, June 2022 E-ISSN: 2580-4537
Pages: 7-14 DOI: 10.13057/asianjagric/g060102

Production of quality seeds of chili using soil amendments

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Manuscript received: 20 November 2021. Revision accepted: 24 January 2022.

Abstract. *Roy K, Khan AA, Rubayet MT, Haque MM. 2022. Production of quality seeds of chili using soil amendments. Asian J Agric 6: 7-14.* The present investigation was conducted to produce quality chili seeds using soil amendments. The soil was amended with vermicompost, colonized *Trichoderma*, mustard oil cake, cow dung, and poultry manure for quality seed production. The fruit yield (3.63 t ha^{-1}) and seed yield (2.40 t ha^{-1}) were higher from colonized *Trichoderma* amended plot. All the organic amendments, such as colonized *Trichoderma*, vermicompost, poultry manure, mustard oil cake, and cow dung, increased the yield of chili seeds compared to the control. Quality characteristics of harvested seeds, such as germination, vigor, and 1,000 seed weight, were found higher in colonized *Trichoderma* amendment plots. Five fungi, namely *Aspergillus* sp., *Fusarium* sp., *Colletotrichum capsici* (Syd. & P.Syd.) E.J.Butler & Bisby, *Curvularia* sp., and *Alternaria alternata* (Fr.) Keissl. were found to be associated with seeds, and the infection rate of different fungi varied from 1.70 to 9.20%. The lowest (9.80%) total seed-borne infection was also recorded in seeds of colonized *Trichoderma* amended plot. The highest (3.73) benefit-cost ratio was obtained from colonized *Trichoderma*, followed by poultry manure (3.39) and vermicompost (3.33) amendment. Thus, soil amendment with colonized *Trichoderma*, vermicompost, or poultry manure is suggested to produce quality chili seeds with a higher yield.

Keywords: Cow dung, mustard oil cake, poultry manure, seed health, *Trichoderma*, vermicompost

INTRODUCTION

Chili is an important spice of the world and is extensively grown in Bangladesh. It belongs to the genus *Capsicum* and the family Solanaceae and is a source of vitamins A, E, and C. Color and flavor extract from chili are used in both food and industries. Some varieties are grown all over Bangladesh in Rabi and Kharif seasons. In 2018-19, the area was 43,947 and 195,256 acres, and the production was 43,452 and 10,602 tons in Kharif and Rabi seasons, respectively (BBS 2020). Quality seed is an essential component of crop production. Farmers mainly depend on their seeds of inferior quality. Poor seed quality is an important factor among the various factors responsible for the low yield of the crop. The application of chemical fertilizers may increase its yield. But the imbalanced and excessive use of chemical fertilizers degrades the soil and the environment (Higa 1991; Lestari et al. 2017; Jaikhisun et al. 2018; Purba et al. 2020). The organic amendments used with water, such as traditional thermophilic composts, have long been used as an effective method to improve soil structure, increase soil fertility, microbial diversity, populations, and activity, improve soil moisture-holding capacity, and increase crop yields (Zink and Allen 1998). Vermicomposting is the best method to recycle solid waste towards achieving sustainable solid waste management. During the passage of organic substrate through the gut, earthworms convert the nutrients from organic matter into bioavailable forms. Various enzymes and hormones are mixed with the digested material, stimulating plant growth and protecting plants from pathogen infestation (Gajalakshmi and Abbasi 2004). *Trichoderma* is a genus of fungus strains that live as symbionts on plant roots and have qualities that encourage plant growth and development (Harman et al. 2004). *Trichoderma* species have long been recognized as bio-agent for controlling plant disease and increasing yield by increasing phytohormones production, such as jasmonic and salicylic acid (Silva et al. 2019). *Trichoderma* as a biological agent may be a cost-effective and efficient technique. Many studies on *Trichoderma* are underway, focusing on their ability to alleviate abiotic stress; nevertheless, the specific knowledge of mechanisms related to their ability to modulate diverse plant abiotic stress factors is still lacking. The commercialization of *Trichoderma* biofertilizer has encouraged farmers. *Trichoderma* is used in all crops, with or without additives; however, when used as an amendment with compost, *Trichoderma* biofertilizer may produce greater results than any other fertilizer. The poultry industry is one of the world's largest and fastest-growing agricultural enterprises. The majority of the litter made by the poultry business is currently used as a source of nutrients and soil amendment on agricultural land (Bolan et al. 2010). It has been applied to surrounding crops and pasturelands to recycle nutrients, primarily nitrogen (N), phosphorus (P), and potash (K) (Lorimor and Xin 1999).

Cow dung is important organic manure. It is also called soil life and is important in sustainable soil fertility and crop productivity. The biggest benefit of cycling and recycling organic matter in soils is the overall soil environment improvement and supply of nutrients, especially N, P, K, and S. Moreover, it provides nutrients and improves soil's physical and chemical properties like porosity and water-holding capacity. In addition, cow dung is a harbor of rich microbial diversity, containing different species of bacteria (*Bacillus* sp., *Corynebacterium* sp., and *Lactobacillus* sp.), protozoa, and yeast (*Saccharomyces* and *Candida*) (Nene and Thapliyal 2002). About 60% of the seed mustard oil cake is generated as a by-product during oil extraction. It is a rich source of nitrogen (4.8%), potassium (as K_2O-1.3%), and phosphorous (as P_2O_5-2%), which are essential requirements to maintain the fertility of the soil and the proper growth of a plant. Organic manure provides several benefits by minimizing production costs and is an environment-friendly cultivation method. Consumers have been increasingly expecting high-quality, safe food and are particularly interested in organic items (Ouda and Mahadeen, 2008). Inorganic fertilizer is made of synthetic materials; when an excess of the application occurs, the soil becomes toxic. However, organic crop additives are becoming more popular as people become more aware of the harmful impacts of inorganic fertilizers on crop productivity and growing environmental and ecological concerns. Considering the above facts, the study aimed to know the effect of various soil amendments on the quality of chili seed production.

MATERIALS AND METHODS

Location of the experimental field

The experiment was conducted from November 2018 to May 2019 at Bangabandhu Sheikh Mujibur Rahman Agricultural University's Plant Pathology field in Gazipur, Bangladesh. The experimental site was located at 24°09 N latitude and 90°26 E longitudes, with an elevation of 8.4 meters above sea level, and it belongs to the Salna series, which represents the sallow Red Brown Terrace soil that falls under the order of inceptisols and the Madhupur Tract's Agro-Ecological Zone (AEZ No. 28).

The climate of the experimental area

In the experimental area, the minimum and maximum air temperature varied between 11 to 27°C and 14 to 34°C, soil temperature in 10 cm, 20 cm, and 30 cm depth varied between 16 to 27.5°C, 16.5 to 28°C, and 17 to 28.5°C, respectively, groundwater table varied between 15.60 m and 18.56 m and the total amount of rainfall was 2.92 mm during the entire cropping period.

The soil of the experimental field

The soil of the study site was silty clay loam to clay loam in texture and belonged to the Madhupur tract's AEZ No. 28, with a pH of 5.8 to 6.5 and an ECE of 25.28 (Haider 1991). The organic carbon and organic matter of the soil sample collected from the experimental area were 0.75 and 1.12, respectively, determined with the help of the Soil Science Department of BSMRAU before applying soil amendments.

Materials collection

Chandra Mukhi chili seeds of Lal Teer, mustard oil cake, and chemical fertilizers were collected from a retailer at Joydebpur in Gazipur. Vermicompost was collected from Pajulia Village at Gazipur. *Trichoderma* culture was taken from the Plant Pathology division of the Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, and poultry manure and cow dung were gathered from the BSMRAU's nearby farm. The chickpea meal substrate was prepared and inoculated with *Trichoderma harzianum* Rifai. The *T. harzianum* was allowed to colonize in a chickpea meal for 21 days (Arefin et al. 2019). After 21 days, the colonized chickpea meal substrate was air-dried and stored in a conical flask a 10°C (Liton et al. 2019; Das et al. 2019). The mustard oil cake was soaked in water for 24 hours and kept in a hole to adjust the soil temperature (Rubayet and Bhuiyan 2016). After three days, the mustard oil cake was ready to incorporate into the soil.

Raising of seedlings

Seedlings of chilies were cultivated in a seedbed. The seedbed was (1.2 m × 3 m) in size. The soil was well prepared and turned into a loose friable, and dry mass using good tilth. All weeds and stubbles were removed, and the soil was amended with well-decomposed cow manure. On 1 November 2018, ten-gram seeds were sown and then covered with light dirt. Within six days of sowing, the seedlings emerged. Weeding and irrigation were performed as needed. Plants were ready for transplanting after 35 days of seed sowing.

Design and layout of the experiment

The experiment was set up in a three-replication randomized complete block design (RCBD). The total area was divided into three equal blocks. Each block consisted of six plots, where six treatments were allotted randomly. There were 18 unit plots in the experiment. The area of a unit plot was 4 m^2, which contained 16 plants at a spacing of 40 cm × 40 cm. The distance between two blocks and two plots was kept at 1.00 m and 0.50 m, respectively.

Land preparation

The soil was thoroughly prepared for agricultural production, and tilth was ensured. The trial field land was ploughed with a motorized tiller and then laddered to achieve the desired tilth. Larger clods were broken into smaller pieces, and the land corners were spaded. After ploughing and laddering, all the stubbles and uprooted weeds were removed, and the land was ready. The field layout and design of the experiment were followed after land preparation.

Application of fertilizers

According to Fertilizer Recommended Guide Bangladesh Agricultural Research Council (BARC), a generalized dose of 1.60 kg TSP, 1.2 kg MoP, and 0.78 kg (half dose) urea fertilizer were given in all units plots at the rate of 223 kg ha^{-1}, 167 kg ha^{-1} and 218 kg ha^{-1}. The rest of the half dose (0.78 kg) of urea fertilizer was applied after 30 days of transplanting.

Treatments of the experiment

The experiment had five treatments for soil amendment. However, the control was maintained where no soil amendment was included. Thus, the experiment had six treatments altogether. In each 4 m^2 plot, 2.00 kg vermicompost (@ 5 t ha^{-1}), 0. 27 kg colonized *Trichoderma* (@ 0.90 t ha^{-1}), 0.80 kg mustard oil cake (@ 2 t ha^{-1}), 4.00 kg cow dung (@ 10 t ha^{-1}) and 2.00 kg poultry manure (@ 5 t ha^{-1}) were applied during final land preparation in the respective plot as per the layout of the experiment.

Transplanting of seedlings

Healthy and uniform 35 days old seedlings were uprooted from the seedbed and were transplanted in the experimental plots on 6 December 2018.

Intercultural operations

After transplanting the seedlings, different intercultural operations were accomplished for better growth and development of the plants. Weeding was accomplished whenever necessary to keep the crop free from weeds. Irrigations were given throughout the growing period by garden pipes and watering canes. The first irrigation was given immediately after the transplantation, while the second was done per requirement.

Harvesting

Fruits were harvested at 6 to 7 days intervals during an early riping stage when they attained marketable size. Harvesting was started on 15 March 2019 and continued until 25 May 2019.

Data collection

Five plants were randomly selected from each plot for data collection to prevent the border effect and achieve the best level of precision. Data on the following parameters were collected from the sample plants during the experiment.

Plant height

The plant height of the selected five plants was measured in cm from the base of the plant to the terminal growth point of the main stem at 65 days of planting up to observe the growth of plants, and the average height was computed.

Number of branches per plant

The number of branches per plant was counted 65 days after transplanting (DAP) from tagged plants. The average of five plants was computed and expressed in an average number of branches per plant.

Number of fruits per plant

The total number of fruits produced in a plant was counted and recorded.

The dry weight of fruits

After harvesting, the fruits were dried in the sunshine. The moisture content was maintained at 9.00%. A digital weighing balance was used to measure the fruit weight of each plot.

The dry weight of seeds

The exocarp was cut with a sharp blade, and the chili seeds were removed from the fruit. A digital weighing balance was used to measure the seed weight of each plot.

Disease incidence

After transplanting the seedlings, data on various diseases like *Cercospora* leaf spot, *Fusarium* wilted plants, and anthracnose of fruits was recorded in each field plot. Then, the percentage of disease incidence was calculated following the formula given below:

$$\%\ \text{disease incidence} = \frac{\text{No. of infected leaves/plants/fruits}}{\text{Total no. leaves/plants/fruits investigated}} \times 100$$

The infected samples of leaves, plants, and fruits were collected in the laboratory, and associated pathogens were isolated and identified.

Quality of harvested seeds

Germination capacity

Germination capacity was determined from four hundred seeds (4×100) into replicates of 100 seeds of each sample sown in blotting paper in a petri dish. After seven days of sowing, results were recorded as a percentage of the number of seeds germinated on the Petri dish. The average percentage was recorded to the nearest whole number. The germination percentage was computed using the following formula:

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Number of seeds tested}} \times 100$$

Seed vigor index

The rate of germination is measured vigor index (VI). First, normal germinated seeds were removed and counted daily. That was started on the first seeding and continued up to 14 days. Then, an index was computed for each replication by dividing the number of germinated seeds removed each day by the day they were removed (Sen and Ghosh 1999). Seed VI can be computed by the following formula (AOSA 1983):

$$\text{Vigour index} = \frac{\text{No. of germinated seeds in first count}}{\text{No. of days to first count}} + \ldots + \frac{\text{No. of germinated seeds in last count}}{\text{No. of days to last count}}$$

Electrical conductivity

Four replications of 50 seeds of each sample were weighted (to the nearest mg) and then soaked in 50 mL de-ionized water for 24 hours at 25±1°C. After 24 hours, the water of the beaker containing seeds was decanted to separate the seeds. The electrical conductivity of the decanted water containing seed leachate was then measured with a conductivity meter (Model-CM-30ET). The electrical conductivity (EC) was expressed in μS/cm.

Thousand seed weight

Thousand seed weight was calculated for each seed sample. First, the seed sample was divided into three sub-samples, and ten replicates of 100 seeds from each sub-sample were counted at random. Thus, the weight of replicates (l00×l0×3 replicates) was added together, and the resulting mean weight was recorded at the 1,000 seeds weight of the seed sample (ISTA 2006).

Seed health test

Regarding fungi associated with chili seeds, seed health was tested following International Rules for Seed Health Testing (ISTA 1976). A sub-sample of 400 seeds was randomly selected from each sample. Seeds were plated on sterilized and moist blotter paper in a 9 cm Petri dish. Twenty-five seeds were plated in each Petri dish, maintaining equal distances from seed to seed. After plating, the seeds were incubated at 25±2°C temperature. The filter paper was kept moist by adding sterilized water whenever necessary. Data on the prevalence of seed-borne fungi grown on the planted seeds were recorded after seven days of incubation. Fungi associated with the seeds were observed under a binocular microscope. Based on the morphological characters, fungi were identified using appropriate keys (Mathur and Kongsdal 2003). When fungus identification was impossible by observing the growth characteristics under a stereo-microscope, temporary mounts were prepared and examined under a compound microscope for detailed morphology. Seeds exhibiting different fungi were expressed in percentage based on the planted seeds.

Statistical analysis

All data were subjected to statistical analysis by analysis of variance (ANOVA). Microsoft Excel and Statistics 10 software programs were used wherever appropriate, and means were compared according to the least significant difference (LSD) test.

RESULTS AND DISCUSSION

Effect of soil amendment on chili seed production

Plant height

The result showed that significantly higher plant height was found in colonized *Trichoderma* amended plot (79.70 cm), followed by vermicompost (75.10 cm), poultry manure (74.6 cm), mustard oil cake (73.00 cm) and cow dung (71.40 cm) amended plots. There were no significant differences among vermicompost, poultry manure, and mustard oil cake amended plots in the context of plant height. The lowest (66.80 cm) plant height was found in the control (Table 1).

Number of branches/plant

A significant maximum number of branches per plant was found in colonized *Trichoderma* treated plot (17.00), followed by vermicompost (15.00), poultry manure (14.00), mustard oil cake (14.00), and cow dung (13.00) amended plots. There were no significant differences in the number of branches/plants in vermicompost, poultry manure, and mustard oil cake-treated plots. The minimum (10.00) number of branches was found in the control treatment (Table 1).

Number of fruits/plant

The maximum number of fruits per plant was found in colonized *Trichoderma* applied plot (171.00), followed by vermicompost (161.00), poultry manure (149.00), mustard oil cake (144.00), and cow dung (140.00) applied plots. There was no significant difference in some fruits per plant in colonized *Trichoderma* and vermicompost applied plots. The minimum (120.00) number of fruits per plant was found in the control (Table 1).

Fruits and seed yield (t ha^{-1})

The highest fruit yield was recorded in the colonized *Trichoderma* applied plot (3.63 t ha^{-1}), which was statistically similar to the vermicompost applied plot (3.53 t ha^{-1}). The yield of chili was statistically similar with vermicompost (3.53 t ha^{-1}), poultry manure (3.50 t ha^{-1}), and mustard oil cake (3.35 t ha^{-1}) applied plot. The lowest (2.08 t ha^{-1}) yield was found in the control. The highest seed yield was recorded in colonized *Trichoderma* applied plot (2.40 t ha^{-1}), followed by the vermicompost applied plot (2.18 t ha^{-1}). The seed yield was statistically similar with vermicompost (2.18 t ha-1), and poultry manure (2.12 t ha^{-1}) applied plots. The lowest (1.35 t ha^{-1}) seed yield was found in the control (Table 1).

Table 1. Effect of different soil amendments on growth and yield parameters of chili

Soil amendments	Height of plants (cm)	Number of branches/plants	Number of fruits/plants	Weight of fruits (t ha^{-1})	Weight of seeds (t ha^{-1})
Control	66.80d	10.00d	120.00d	2.08d	1.35 e
Vermicompost	75.10b	15.00b	161.00ab	3.53ab	2.18b
Colonized *Trichoderma*	79.70a	17.00a	171.00a	3.63a	2.40a
Mustard oil cake	73.00bc	14.00bc	144.00c	3.35b	2.00c
Cow dung	71.40c	13.00c	140.00c	2.45c	1.55d
Poultry manure	74.60b	14.00b	149.00bc	3.50ab	2.12b
CV (%)	2.29	5.44	6.21	4.06	4.78

Note: Means followed by the same letter (s) in a column are not significantly different at a 5% level

Percentage of increase in fruit and seed yield of chili

Results revealed that all the treatments under soil amendments increased the fruit and seed yield significantly compared to the control, but their efficacy was not similar. The highest fruit yield was increased in colonized *Trichoderma* (74.00%) treated plots, followed by vermicompost (69.00%), poultry manure (68.00%), and mustard oil cake (61.00%) treated plots. The cow dung-treated plot recorded the lowest (17.00%) fruit yield increase (Figure 1). The highest seed yield increase was recorded in colonized *Trichoderma* (77.00%) treated plots, followed by vermicompost (61.00%), poultry manure (57.00%), and mustard oil cake (48.00%) treated plots. The lowest (15.00%) seed yield increase was recorded in the cow dung-treated plot (Figure 2). Molla et al. (2012) reported an above 200% yield increase was recorded by BioF/Compost (household/ kitchen/wastes composted by *Trichoderma*) over the control, but a 30.40% yield increase was recorded by BioF/Compost over the standard dose of N:P:K. Rahaman et al. (2012) experimented with an 18% yield increase recorded by cow dung over a standard dose of N:P:K in field studies of chili. Hassan et al. (2013) showed that a 35.00% yield was increased by poultry manure as soil amendment over the standard dose of N:P:K. The present experimental results agreed with the previous findings of various researchers (Molla et al. 2012; Rahman et al. 2012; Simi et al. 2019) as the soil amendment increases the yield of chili fruits and seeds.

Disease incidence

Three diseases, *Cercospora* leaf spot, *Fusarium* wilt, and anthracnose of fruits, were recorded in the experimental chili field. The causal organism of diseases identified *Cercospora capsici* Heald & F.A.Wolf, *Fusarium oxysporum* Schltdl. and *Colletotrichum capsici* (Syd. & P.Syd.) E.J. Butler & Bisby, respectively (Table 2).

Incidence of *Cercospora* leaf spot

The highest *Cercospora* leaf spot was recorded in the control plot (10.83%), followed by cow dung (8.41%), mustard oil cake (6.83%), and poultry manure treated plot (4.50%). The lowest incidence of *Cercospora* leaf spot was recorded in colonized *Trichoderma* (3.00%) treated plot, followed by the vermicompost (4.42%) treated plot (Table 2).

Incidence of wilt-infected plants

The highest *Fusarium* infected plants were observed in the control plot (18.75%), followed by cow dung (10.40%), poultry manure (8.30%), mustard oil cake (6.25%), and vermicompost (6.25%) treated plot. The disease incidence was statistically similar in vermicompost, poultry manure, and mustard oil cake-treated plot. The lowest (2.10%) *Fusarium*-infected plant was observed in colonized *Trichoderma*-treated plot (Table 2).

Incidence of anthracnose in chili fruits

The highest anthracnose-infected fruits were recorded in the control plot (11.41%), followed by cow dung (7.91%), mustard oil cake (6.91%), poultry manure, and vermicompost (5.16%) applied plot. The lowest anthracnose was recorded in colonized *Trichoderma* (2.91%) applied plot, followed by the vermicompost (5.16%) applied plot (Table 2).

Quality of harvested seeds under soil amendments

Germination percentage

The highest germination was recorded in seeds collected from *Trichoderma* amended plot (77.00%), followed by vermicompost (70.00%). The germination percentage of harvested seeds collected from the soil-amended plot with poultry manure, mustard oil cake, and cow dung was 69.00%, 67.00%, and 65.00%, respectively. The germination percentage of harvested seeds collected from vermicompost and poultry manure amended plot was statistically similar. The lowest germination percentage was recorded in the seeds of the control plot (63.00%), which was statistically similar to the cow dung (65.00%) amended plot (Table 3).

Vigor index (VI)

Vigor indices of seeds collected from six treatments ranged from 28.50-40.50. The highest VI was recorded in colonized *Trichoderma* (40.50) amended plot, followed by vermicompost (37.58), poultry manure (35.40), mustard oil cake (33.84), and cow dung (29.40) amended plots. But VI of seeds harvested from poultry manure and mustard oil cake amended plots was statistically similar. The control plot recorded harvested seeds' lowest (28.50) VI (Table 3).

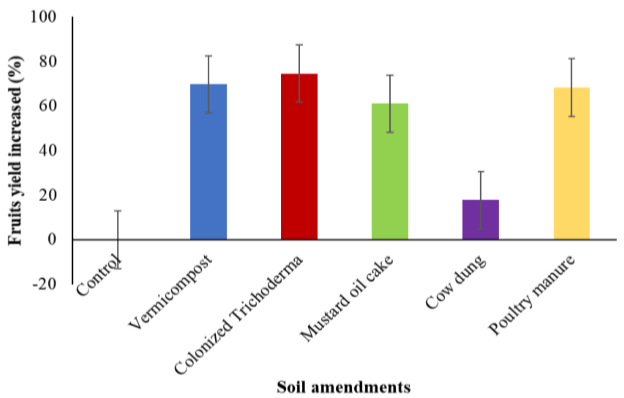

Figure 1. Increased percentage of fruit yield under different soil amendments over the control

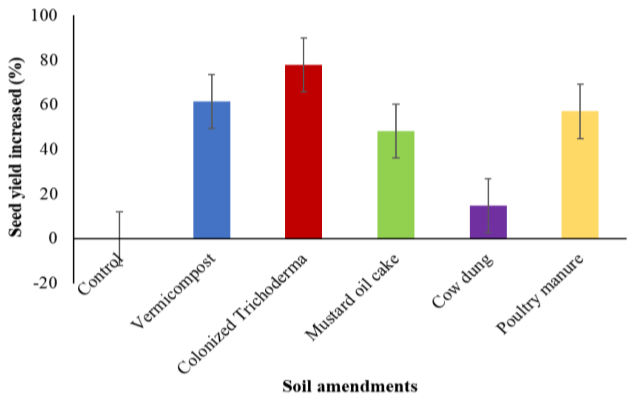

Figure 2. Increased percentage of seed yield under different soil amendments over the control

Electrical conductivity

The electrical conductivity of seeds harvested from soil amended field varied from 0.11 to 0.18 µS cm^{-1}. The lowest electrical conductivity was recorded in colonized *Trichoderma* treated plot (0.11 µS cm^{-1}), followed by vermicompost (0.13 µS cm^{-1}), poultry manure (0.14 µS cm^{-1}), mustard oil cake (0.14 µS cm^{-1}) and cow dung (0.15 µS cm^{-1}) treated plots. Regarding electrical conductivity, there was no significant difference among vermicompost, poultry manure, and mustard oil cake-treated plots. The electrical conductivity of seeds harvested from poultry manure, mustard oil cake, and cow dung-treated plots was also statistically similar. The maximum (0.18 µS cm^{-1}) electrical conductivity was recorded in the control (Table 3).

Thousand seed weight

The thousand seed weights of harvested seeds collected from soil-amended fields ranged from 3.90 to 4.80 g. The highest thousand seed weight was obtained from colonized *Trichoderma* amended plot (4.80 g), followed by vermicompost (4.60 g), poultry manure (4.53 g), mustard oil cake (4.40 g) and cow dung (4.10 g) amended plot. The thousand seed weights of vermicompost and poultry manure amended plots were statistically similar. The lowest (3.90 g) thousand seed weight was recorded in the control plot (Table 3).

Prevalence of seed-borne fungi of harvested seeds

Total seed-borne fungal infection in harvested chili seeds ranged from 9.80 to 39.70%. The highest infection was recorded in the control plot (39.70%), followed by cow dung (30.10%), mustard oil cake (23.50%), poultry manure (17.75%), and vermicompost (16.60%) amended plot. The lowest (9.80%) fungal infection was recorded in seeds of colonized *Trichoderma* amended plot. The identified fungal species were *Aspergillus* sp., *Fusarium* sp., *Curvularia* sp., *Co. capsici*, and *Alternaria alternata* (Fr.) Keissl. (Table 4). The most predominant fungus was *Aspergillus* sp., ranging between 4.50 to 9.00%. The highest *Aspergillus* sp. was found in control (9.00%), followed by the amended plot of cow dung (7.50%). The prevalence of *Aspergillus* sp. in seeds was statistically similar in cow dung (7.50%) and mustard oil cake (6.30%) amended plots and vermicompost (3.90%) and poultry manure (4.50%) amended plot. The lowest (2.00%) *Aspergillus* sp. infection was recorded in colonized *Trichoderma* amended plot (Table 4). The second most fungi recorded in seeds was *Fusarium* sp. ranging from 2.10 to 9.20%. The highest *Fusarium* sp. infection was recorded in seeds of the control plot (9.20%), followed by cow dung (6.10%), mustard oil cake (4.90%), vermicompost (3.90%), poultry manure (3.30%) amended plot. The lowest (2.10%) fungal infection was recorded in colonized *Trichoderma* amended plot (Table 5). The highest incidence of *Co. capsici* was recorded in seeds harvested from the control plot (7.70%), followed by cow dung (5.80%), mustard oil cake (4.20%), poultry manure (3.10%), vermicompost (2.80%), amended plot. Among them, mustard oil cake (4.20%), poultry manure (3.10%), and vermicompost amended plot (2.80%) were statistically similar. The lowest incidence of Co. capsici was recorded in seeds of colonized *Trichoderma* (1.70%) amended plot, which was statistically similar to the vermicompost (2.80%) amended plot. Curvularia sp.'s prevalence in seeds varied from 1.90-6.80%. The highest incidence of *Curvularia* sp. was found in the control plot (6.80%), followed by cow dung (4.80%), mustard oil cake (4.00%), and poultry manure (3.25%) amended plot. The lowest (1.90%) incidence of *Curvularia* sp. was recorded in seeds of colonized *Trichoderma* amended plot. The prevalence of *Alternaria* varied from 2.10 to 7.00%. The highest *A. alternata* infection was noted in seeds of the control plot (7.00%), followed by cow dung (5.90%), mustard oil cake (3.90%), poultry manure (3.60%), vermicompost (3.10%) amended plot. Among them, vermicompost and colonized *Trichoderma* amended plots were statistically similar. The lowest (2.10%) *Alternaria* infection was recorded in seeds of colonized *Trichoderma* amended plot (Table 4).

Table 2. Percentage of different disease incidences of chili in the field under soil amendments

Soil amendments	*Cercospora*-affected leaves (%)	*Fusarium* wilted plants (%)	Anthracnose-affected fruits (%)
Control	10.83a	18.75a	11.41a
Vermicompost	4.42d	6.25b	5.16d
Colonized *Trichoderma*	3.00e	2.10c	2.91e
Mustard oil cake	6.83c	6.25bc	6.91c
Cow dung	8.41b	10.4b	7.91b
Poultry manure	4.50d	8.30bc	5.25d
CV (%)	7.07	48.33	8.71

Note: Means followed by the same letter (s) in a column are not significantly different at a 5% level

Table 3. Effect of different soil amendments on quality parameters of harvested chili seeds

Soil amendments	Germination (%)	Vigor index	Electrical conductivity (µS cm^{-1})	Thousand seed weight (g)
Control	63.00d	28.50e	0.18a	3.90e
Vermicompost	70.00b	37.58b	0.13c	4.60b
Colonized *Trichoderma*	77.00a	40.50a	0.11d	4.80a
Mustard oil cake	67.00c	33.65c	0.14bc	4.40c
Cow dung	65.00d	29.40d	0.15b	4.10d
Poultry manure	69.00bc	35.40c	0.14bc	4.53b
CV (%)	1.45	3.71	7.0	1.33

Note: Means followed by the same letter (s) in a column are not significantly different at a 5% level

Table 4. Incidence of fungi associated with seeds produced by soil amendments

Soil amendments	Seed-borne fungi (%)					
	***Aspergillus* sp.**	***Colletotrichum capsici***	***Fusarium* sp.**	***Curvularia* sp.**	***Alternaria alternata***	**Total**
Control	9.00a	7.70a	9.20a	6.80a	7.00a	39.70
Vermicompost	3.90c	2.80cd	3.90d	2.60e	3.10d	16.30
Colonized *Trichoderma*	2.00d	1.70d	2.10e	1.90f	2.10e	9.80
Mustard oil cake	6.30b	4.20c	4.90c	4.00c	3.90c	23.30
Cow dung	7.50b	5.80b	6.10b	4.80b	5.90b	30.10
Poultry manure	4.50c	3.10c	3.30d	3.25d	3.60cd	17.75
CV (%)	12.32	17.23	9.49	8.41	10.78	

Note: Means followed by the same letter (s) in a column are not significantly different at a 5% level

Percentage of reduction in total seed-borne fungi of chili

Results of soil amendments with six treatments, namely vermicompost, colonized *Trichoderma*, poultry manure, mustard oil cake, and cow dung against seed-borne fungi of chili, are presented in Figure 3. All the soil amendments significantly reduced the percent seed-borne infection of total fungi (*Aspergillus* sp., *Co. capsici*, *Fusarium* sp., *Curvularia* sp., and *A. alternata*) compared to the control plot. The reduction percentage of fungi varied from 24.00 to 75.00%. The highest reduction percentage was obtained by colonized *Trichoderma* amendment (75.00%), followed by vermicompost (59.00%), poultry manure (55.00%), mustard oil cake (41.00%), and cow dung amendment (24.00%) (Figure 3). The experiment results suggested that organic soil amendments and application of colonized *Trichoderma* in soil reduced disease incidence of chili in the field and reduced the seed-borne pathogens in harvested seeds. Different researchers also reported that organic soil amendments and colonized *Trichoderma* reduce disease incidence (Kapoor 1996; Punja et al. 2002; Prasad et al. 2002; Kashem et al. 2005; Hassan et al. 2013; Sultan and Guffar 2013; Tapwal et al. 2015). Sultana and Ghaffar (2013) reported that maximum increase in plant size (20.00 cm), seed germination (86.00%), and up to 2.20% reduction in seedling mortality caused by *Fusarium* sp. in cucumber by mustard oil cake in the field study.

Kapoor (1996) found groundnut and mustard oilcake at a 2.00 % concentration of soil (w/w) was most effective in reducing pathogen population (>70%) and disease incidence. Hassan et al. (2013) reported that 63.30% anthracnose and 5.00% *Cercospora* leaf spot reduction were obtained using poultry manure as a soil amendment. Punja et al. (2002) evaluated greenhouse waste, windrow dairy solids, vermicompost dairy solids, and commercially available biological control agents to reduce disease incidences of *Fusarium* root and stem rot caused by *F. oxysporum* f.sp. *radicis-cucumerinum*, and *Pythium* damping-off and crown rot, caused by *Pythium aphanidermatum* (Edson) Fitzp. They reported that all three composts reduced root and stem rots to some degree, and autoclaved compost lost its suppression, suggesting the microbial antagonism involved. Prasad et al. (2002) found that soil treated with *T. harzianum* showed 61.50% disease control in chickpeas, while Kashem et al. (2005) observed about 30.00% disease control in lentil seeds. Tapwal et al. (2015) found that *T. harzianum* recorded maximum growth inhibition (34.20%) against *A. alternata*, followed by *F. oxysporum* (27.04%), *Cochliobolus lunatus* R.R.Nelson & F.A.Haasis (25.64%), *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. (15.00%) and minimum for *Rhizoctonia solani* J.G.Kühn (5.10%). Bhat et al. (2016) reported that *T. harzianum* inhibited mycelia growth by 40.00 to 50.00% in vitro and increased yield up to 30.00% in the Haveri District, while at Bellary, *T. harzianum* reduced wilt incidence by 39.70%.

Benefit-cost ratio

The benefit-cost ratio obtained from different soil amendments, including control, varied from 1.98 to 3.73. The highest (3.73) benefit-cost ratio was obtained from colonized *Trichoderma* amendment soil, followed by poultry manure (3.39), vermicompost (3.33), mustard oil cake (2.83), and cow dung (2.31) amendment and the lowest (1.98) benefit-cost ratio was obtained from control (Table 5).

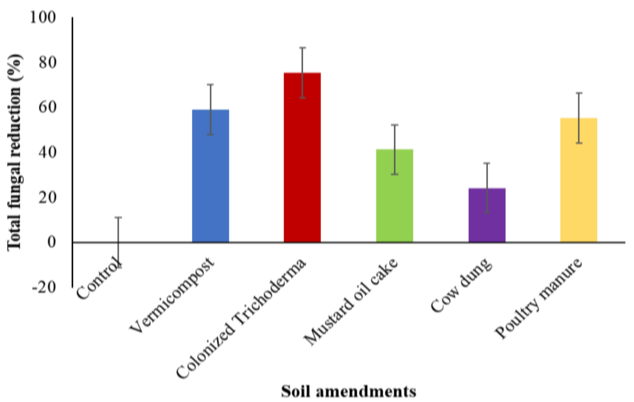

Figure 3. Percentage of reduction of total seed-borne fungi under different soil amendments over the control

Table 5. The benefit-cost ratio of soil amendments and the control

Soil amendments	Cost (Tk. ha^{-1})	Selling price (Tk. ha^{-1})	Benefit-cost ratio
Control	136561	270000	1.98
Vermicompost	166561	555000	3.33
Colonized *Trichoderma*	160861	600000	3.73
Mustard oil cake	176561	500000	2.83
Cow dung	156561	362500	2.31
Poultry manure	156561	530000	3.39

In conclusion, growth characteristics like plant height, the number of branches, and fruit and seed yield were the highest in the colonized *Trichoderma* amended plot, followed by the vermicompost amended plot. The disease incidence of *Cercospora* leaf spot, *Fusarium* wilt, and anthracnose of fruits was minimum in colonized *Trichoderma* amended plot. The highest seed yield was increased by colonized *Trichoderma* soil amendment (77.00%), followed by vermicompost (61.00%) and poultry manure (57.00%) amendment. The quality of harvested seeds was better in colonized *Trichoderma* and vermicompost amended plots.

REFERENCES

Arefin MN, Bhuiyan MKA, Rubayet MT. 2019. Integrated use of fungicide, plant extract and bio-agent for management of *Alternaria* blight disease of radish (*Raphanus sativus* L.) and quality seed production. Res Agric Vet Sci 3 (1): 10-21.

Association of Official Seed Analysts (AOSA). 1983. Seed Vigor Testing Handbook. Contribution No. 32 to the Handbook on Seed Testing. The Association, Ithaca, New York, USA.

Bangladesh Bureau of Statistics (BBS). 2020. Statistical Yearbook of Bangladesh. Statistics Division, Ministry of Planning, Dhaka, Government of the People's Republic of Bangladesh, Bangladesh.

Bhat MN, Mesta R, Yenjerappa ST, Tatagar MH, Sardana HR, Singh D, Ahmad M. 2016. Biological control of *Fusarium* wilt of chilies using *Trichoderma* sp. Indian J Hortic 73 (1): 74-77. DOI: 10.5958/0974-0112.2016.00021.9.

Bolan NS, Szogi AA, Chuasavathi T, Seshadri B, Rothrock Jr MJ, Panneerselvam P. 2010. Uses and management of poultry litter. World's Poult Sci J 66 (4): 673-698. DOI: 10.1017/S0043933910000656.

Das IR, Bhuiyan MKA, Jannat R, Kayesh E, Rubayet MT, Arefin MN. 2019. Effect of bio-fortified compost in controlling soil-borne diseases of lentil (*Lens culinaris* L.) and enhance the crop growth and yield. Adv Biol Earth Sci 4 (2): 93-106.

Gajalakshmi S, Abbasi SA. 2004. Earthworms and vermicomposting. Indian J Biotechnol 3: 486-494.

Haider EA. 1991. Agro ecological region of Bangladesh. Land resources appraisal of Bangladesh Agricultural Development. Plant Physiol 35: 426-439.

Harman GE, Howell CR, Viterbo A, Chet I, Lorito M. 2004. *Trichoderma* species opportunistic, avirulent plant symbionts. Nat Rev Microbiol 2 (1): 43-56. DOI: 10.1038/nrmicro797.

Hassan MR, Hossain I, Islam MR, Khokon MAR. 2013. Comparative efficacy of compost, compost tea, poultry litter and bavistin in controlling diseases of chili. Prog Agric 24 (1-2): 39-44. DOI: 10.3329/pa.v24i1-2.19096.

Higa T. 1991. Effective Microorganisms: A Biotechnology for Mankind. In Proceedings of the First International Conference on Kyusei Nature Farming. US Department of Agriculture, Washington, DC, USA.

International Seed Testing Association (ISTA). 1976. International Rules for Seed Testing. International Seed Testing Association (ISTA), Zurich, Switzerland.

International Seed Testing Association (ISTA). 2006. International Rules for Seed Testing. International Seed Testing Association, Bssersdorf, Switzerland.

Jaikishun S, Hoosein A, Ansari AA. 2018. The effects of vermicompost and vermiwash from the medicinal plants, neem (*Azadirachta indica*) and lime (*Citrus aurantifolia*), on the growth parameters of lettuce in a hydroponic system. Nusantara Bioscience 10: 91-95. DOI: 10.13057/nusbiosci/n100205.

Kapoor U. 1996. Effect of oil cake amendment of soil on tomato wilt caused by *Fusarium oxysporum* f. sp. *lycopersici*. Indian Phytopathol 49 (4): 355-361.

Kashem MA, Naznin HA, Islam MM, Jalaluddin M, Hossain I. 2005. Effect of different methods of application of *Trichoderma* in controlling foot and rot of lentil. Bangladesh J Seed Sci Technol 9 (1-2): 39-42.

Lestari SAD, Sutrisno, Kuntyastuti H. 2017. Short Communication: Effect of organic and inorganic fertilizers application on the early-medium maturing soybean yield. Nusantara Biosci 10: 1-5. DOI: 10.13057/nusbiosci/n100101.

Liton MJA, Bhuiyan MKA, Jannat R, Ahmed JU, Rahman MT, Rubayet MT. 2019. Efficacy of *Trichoderma*-fortified compost in controlling soil-borne diseases of bush bean (*Phaseolus vulgaris* L.) and sustainable crop production. Adv Agric Sci 7 (2): 123-136.

Lorimor JC, Xin H. 1999. Manure production and nutrient concentrations from high rise layer houses. Appl Eng Agric 15 (4): 337-340. DOI: 10.13031/2013.5787.

Mathur SB, Kongsdal O. 2003. Common Laboratory Seed Health Testing Methods for Detecting Fungi. International Seed Testing Association, Basserdorf, Switzerland.

Molla AH, Haque MM, Haque MA, Ilias GNM. 2012. *Trichoderma*-enriched biofertilizer enhances production and nutritional quality of tomato (*Lycopersicon esculentum* Mill.) and minimizes NPK fertilizer use. Agric Res 1 (3): 265-272. DOI: 10.1007/s40003-012-0025-7.

Nene YL, Thapliyal PN. 2002. Fungicides in Plant Diseases Control. Oxford and IBM Publishing Co. Pvt. Ltd., New Delhi, India.

Ouda BA, Mahadeen AY. 2008. Effect of fertilizers on growth, yield, yield components, quality and certain nutrient contents in broccoli (*Brassica oleracea*). Intl J Agric Biol 10 (6): 627-632.

Prasad RD, Rangeshwaran R, Anuroop CP, Rashmi HJ. 2002. Biological control of wilt and root rot of chickpea under field conditions. Ann Plant Prot Sci 10 (1): 72-75.

Punja ZK, Rose S, Yip R. 2002. Biological control agents and composts suppress *Fusarium* and *Pythium* root rots on greenhouse cucumbers. Bulletin OILB/SROP 25 (10): 93-96.

Purba JH, Wahyuni PS, Zulkarnaen, Sasmita N, Yuniti IGD, Pandawani NP. 2020. Growth and yield response of shallot (*Allium ascalonicum* L. var. Tuktuk) from different source materials applied with liquid biofertilizers. Nusantara Biosci 12: 127-133. DOI: 10.13057/nusbiosci/n120207.

Rahman SU, Lawrence R, Kumar EJ, Badri ZA. 2012. Comparative efficacy of *Trichoderma* viride, *T. harzianum* and carbendazim against damping-off disease of cauliflower caused by *Rhizoctonia solani* Kuehn. J Biopestic 5 (1): 23-27.

Rubayet MT, Bhuiyan MKA. 2016. Integrated management of stem rot of potato caused by *Sclerotium rolfsii*. Bangladesh J Plant Pathol 32 (1&2): 7-14.

Sen S, Ghosh, N. 1999. Seed Science Technology. Kalyani Publishers, Ludhiana, New Delhi, India.

Silva BB, Banaay CG, Salamanez K. 2019. *Richoderma*-induced systemic resistance against the scale insect (*Unaspis mabilis* Lit & Barbecho) in Lanzones (*Lansium domesticum* Corr.). Agric For 65 (2): 59-78. DOI: 10.17707/AgricultForest.65.2.05.

Simi SA, Jannat R, Rubayet MT, Bhuiyan MKA. 2019. Efficacy of bio-fortified compost in controlling anthracnose disease of chili caused by *Colletotrichum capsici* and improvement the crop production. Sch Acad J Biosci 7 (12): 482-489.

Sultana N, Ghaffar A. 2013. Effect of fungicides, microbial antagonists and oil cakes in the control of *Fusarium oxysporum*, the cause of seed rot and root infection of bottle gourd and cucumber. Pak J Bot 45 (6): 2149-2156.

Tapwal A, Thakur G, Chandra S, Tyagi A. 2015. In-vitro evaluation of *Trichoderma* species against seed-borne pathogens. Intl J Biol Chem Sci 1 (10): 14-19.

Zink TA, Allen MF. 1998. The effects of organic amendments on the restoration of a disturbed coastal sage scrub habitat. Restor Ecol 6 (1): 52-58. DOI: 10.1046/j.1526-100x.1998.00617.x.