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Effect of *Bacillus subtilis*, Soil Amendments and Microalgae Treatment on *Fusarium equiseti* of Turmeric (*Curcuma longa* L.) Prayagraj, India

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Rhizome rot of turmeric caused by *Fusarium equiseti* emerge as a significant soil-borne threat to crop health. An experiment was conducted to evaluate the effect of *Bacillus subtilis*, soil amendments and microalgae treatment on *Fusarium equiseti* of Turmeric (*Curcuma longa* L). Experiment was conducted under field condition at the courtyard of department of Plant Pathology, SHUATS, Prayagraj, during kharif season of 2022. Various soil treatments including farm yard manure (FYM), spent mushroom compost (SMC), and microalgae were used, along with rhizome treatment utilizing *Bacillus subtilis*. The experiment was carried out in Randomized Block design

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(RBD) with three (3) replications. Results revealed that in the soil application, (T_5) i.e., the combination of all the treatments recorded minimum disease intensity (59.26%) which was significant over other treatments and control (T_0) (33.86%). To evaluate the radial growth (mm) of *Fusarium equiseti* in turmeric, seven botanicals from Manipur viz., *Zanthoxylum acanthopodium*, *Phlogacanthus thyrsiformis*, *Solanum xanthocarpum*, *Centella asiatica*, *Drymaria cordata*, *Persicaria chinensis* and *Gynura cusimbua* were investigated *in vitro* at 10% and 30% concentration. The antagonistic effects of various botanicals were evaluated *in vitro*, demonstrating inhibition of mycelial growth. Among the tested botanicals, *Zanthoxylum acanthopodium* inhibited the highest inhibition rate (86.27%), followed by *Phlogacanthus thyrsiformis* (77.45%), *Solanum xanthocarpum* (75.48%), *Persicaria chinensis* (68.62%), *Drymaria cordata* (65.68%), *Gynura cusimbua* (62.74%) with *Centella asiatica* displaying the lowest inhibition rate (57.84%), all at a concentration of 30%. Overall, our findings highlight the potential of integrated management strategies involving biological control agents and soil amendments for sustainable management of *Fusarium equiseti* in turmeric cultivation. Implementation of these strategies holds promise for improving crop health, productivity, and sustainability in turmeric production systems.

Keywords: Turmeric; rhizome rot; Fusarium equiseti; botanicals; In vitro; microalgae; Solanum xanthocarpum; subtropical regions.

1. INTRODUCTION

Turmeric (*Curcuma longa L.*), a member of the Zingiberaceae family, is a perennial plant characterized by its erect growth habit and abundant foliage [1]. With a maximum height of up to 1 meter, it features a compact stem, oblong leaves with pointed tips, and vibrant funnel-shaped yellow flowers. Widely distributed across tropical and subtropical regions, turmeric is predominantly cultivated in Asian nations, notably India and China [2,3]. Dry turmeric is comprised of approximately 69.43% carbohydrates, 6.3% proteins, 5.1% oils, and 3.5% minerals, alongside other essential elements. Thus, far about 235 compounds, predominantly phenolics and terpenoids, have been discovered in different turmeric species.[4]

The global turmeric production stands at approximately 11 lakh tonnes annually, with India leading as the largest producer and exporter, accounting for 80% of the world's output. The distribution of global production consists of 78% from various regions, with China contributing 8%, Myanmar 4%, and Nigeria and Bangladesh together contributing 6%. Other significant contributors include China, Myanmar, Nigeria, Bangladesh, Pakistan, Sri Lanka, Taiwan, Burma, Indonesia, Malaysia, Vietnam, Thailand, and Central America. India's turmeric industry alone contributes about 78% to global production and 60% to turmeric exports [5]. Telangana emerges as the primary state for both turmeric cultivations, covering 51 thousand hectares, and production, yielding 294 thousand metric tons, contributing 27.84% to the nation's total output in the 2016-17 period. [6] Other notable turmeric-producing states include Maharashtra (177.85 thousand MT), Tamil Nadu (112.59 thousand MT), and Andhra Pradesh (79.73 thousand MT) [7]. Turmeric holds significant economic value in the North Eastern Hill Region (NEHR), with a cultivation area of 38.6 thousand hectares and a production of 93.16 thousand tons, although lower than the national average [8]. Among the NEHR states, Assam leads in turmeric cultivation area (17.63 thousand ha), followed by Mizoram and Sikkim. In terms of production, Mizoram leads with 29.51 thousand tons, followed by Assam and Sikkim [6]. Assam and Sikkim also contribute significantly to the gross domestic product (GDP) through their turmeric production. Collectively, these states' contributions to the GDP from turmeric cultivation play a vital role in the regional and national economy, supporting livelihoods and agricultural sustainability in the NEHR region.

Despite its economic importance to the GDP, turmeric is prone to many fungal, bacterial, viral and nematode diseases. Turmeric is vulnerable to various diseases including leaf spot, anthracnose and rhizome rot. [9] *Fusarium* species are recognized as significant soil-borne plant pathogens, widely prevalent in diverse sources including air, soil, plants, marine ecosystems and fresh water. Among these species, *F. equiseti* is responsible for causing wilt diseases in variety of plant hosts such as grafted watermelon, grapes, cucumber, tomato, cowpea, bean, potato [10,11].

Fig. 1. Symptoms of disease on turmeric plants and rhizome (infected plants; infected rhizome).

Presently, the widespread use of chemical compounds without discrimination has had a profound effect on the environment and has created health hazards. Consequently, plant-based pesticides have gained importance as an alternative to synthetic chemicals due to their lack of threat to the natural environment, human health, and animal welfare. Plants contribute to 75% of molecular medicines either directly or indirectly [12,13]

1.1 Symptoms

In early stage, the central portion of the leaves retains its green color, whereas the edges turn yellow. Mild yellowing occurs at the tips of lower leaves, accompanied by foliage drying, indicative of the crop reaching maturity. Upon cutting open infected rhizomes, affected areas usually exhibit a dull brown or dark appearance.

2. MATERIALS AND METHODS

The experiment was carried out at the courtyard of the Department of Plant Pathology, Sam Higginbottom University of Agriculture, Technology and Sciences, Allahabad, U.P, during the kharif season of 2022-2023. The location is situated at 25°27 North latitude, 80°50 East longitude, and an altitude of 98 meters above sea level. The climate is typically semi-arid and sub-tropical. The present study was carried out to know the efficacy of botanicals against *Fusarium equiseti* and to evaluate the effect of organic matter and microalgae on disease intensity, plant growth parameters and turmeric yield. Organic amendments such as Farm yard manure (FYM), spent mushroom compost (SMC), microalgae and combination of all three were used during experiment. Experimental plot of size 2 m^2 was prepared. Before transplanting, the rhizomes were first treated with *Bacillus subtilis* @ 0.01 g in 1 liter of water. The organic amendments i.e. FYM and SMC were applied to soil and mixed at different dosage before sowing. Microalgae @ 4 g/2 m^2 were mixed with water and then applied after germination of plant at the rhizosphere area of the plant. Microalgae was applied after 15 days interval for the second and third application. For *in vitro,* seven botanicals from Manipur viz., *Xanthoxylum acanthopodium*, *Phlogacanthus thyrsiformis*, *Solanum xanthocarpum*, *Persicaria chinensis*, *Drymaria cordata*, *Gynura cusimbua*, *Centella asiatica* were used for poison food technique.

2.1 Preparation of Botanical Extract

The fresh selected samples (leaves) were collected and cleansed thoroughly with clean water and air dried. The dried leaves were then blended into powder and sterile distilled water was added to it in equal amount. The soaked medicinal powder was first filtered with muslin cloth, then with whatman filter paper and further centrifuged at 1500 rpm for 20 minutes. The clean suspended solution were transferred into 100 ml conical flask and sterilized in an autoclave under 15 lbs pressure for 20 minutes to create a stock solution. Further, each botanical stock solution were used at two concentrations i.e., 10 % and 30 % and were later tested on the radial growth of *F. equiseti* in 24 hrs, 48 hrs and 72 hrs after inoculation [14,15].

2.2 Isolation of *Fusarium equiseti*

The collected plant samples (rhizome) were washed with water, sections with symptoms measuring 2 mm were cut off, and then surface sterilized using 0.1% mercuric chloride for 5-10 seconds. Subsequently, they were rinsed twice with sterilized distilled water to eliminate any residues of mercuric chloride, dried using sterile filter paper, and transferred onto petri plates containing potato dextrose agar media (four pieces per plate). The plates were then incubated for seven days at a temperature of 25±1ºC [16]. The fungus cultures were inoculated onto sterilized petri plates and PDA slants, and maintained in the laboratory at 28±1°C for a period of 15 days. These mother culture slants were preserved at 4°C in a refrigerator. Furthermore, they were sub-cultured monthly and utilized for future experiments.

2.3 Identification and Morphological Characteristics of *Fusarium equiseti*

Using a sterile needle, a small segment of the culture was extracted and placed onto a sterile glass slide. Subsequent staining with lactophenol and cotton blue facilitated the microscopic examination of fungal structures, morphology and culture traits. Initially, a dense white mycelium was formed, later transitioning to a yellowish to buff brown coloration. After 6 days in culture, macroconidia were observed, presenting 3–7 septa with tapered and elongated apical cells and distinctive foot-shaped cells. Chlamydospores appeared thick, intercalary, and abundant in chains or clusters, exhibiting ellipsoidal or globose shapes. Microconidia were absent. Based on morphological and pathological characteristics, the fungus was identified as *Fusarium equiseti* (Corda) Sacc [17].

Identification of the pathogen species was confirmed through National Fungal Culture Collection of India (NFCCI) located at Agharkar Research Institute, Pune. The genetic data obtained from analysis of ITS-rDNA sequences was recorded in GenBank under accession number PP346165.

>TR-1 *Fusarium equiseti* genes for ITS1

TCCGTAGGTGAACCTGCGGAGGGATCATTAC
CGAGTTTACAACTCCCCAAACCCCTGTGAAC
AT
ACCTATACGTTGCCTCGGCGGATCAGCCCGC
GCCCTGTAAAAAGGGACGGCCCGCCCGAGG
ACC
CTAAACTCTGTTTTTAGTGGAACTTCTGAGTA
AAACAAACAAATAAATCAAACTTTCAACAACG
GATCTCTTGGTTCTGGCATCGATGAAGAACG
CAGCAAATGCGATAAGTAATGTGAATTGCAGA
A
TTCAGTGAATCATCGAATCTTTGAACGCACAT
TGCGCCCGCCAGTATTCTGGCGGGCATGCCT
G
TTCGAGCGTCATTTCAACCCTCAAGCTCAGC
TTGGTGTTGGACTCGCGGTAACCCGCGTTCC
CC
AAATCGATTGGCGGTCACGTCGAGCTTCCAT
AGCGTAGTAATCATACACCTCGTTACTGGTAA
T
CGTCGCGGCCACGCCGTAAAACCCCAACTTC
TGAATGTTGACCTCGGATCAGGTAGGAATAC
CC
GCTGAACTTAAGCATATCAATAAGCGGAGGA

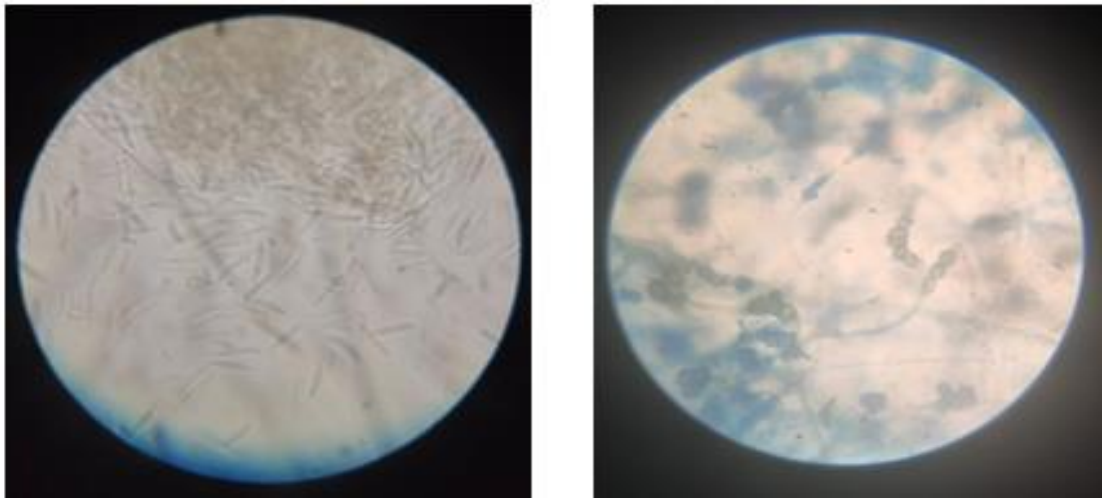

Fig. 2. Microscopic view of *Fusarium equiseti*

Fig. 3. Pure culture of *Fusarium equiseti* in Petri plate and slants.

2.4 Maintenance of Culture

The fungus cultures were sub-cultured on sterilized petri plates and PDA slants and maintained in the laboratory at a temperature of 28±1°C for a period of 15 days. These mother culture slants were preserved in a refrigerator at 4°C. Furthermore, they were sub-cultured monthly and utilized for future experiments.

2.5 Poison Food Technique

The antifungal activity of plant extract was assessed against the pathogen in a laboratory setting using a completely randomized design (CRD) and the poisoned food technique. The plant extract filtrate was added to PDA to achieve concentrations of 10% and 30%, mixed thoroughly, and poured into Petri dishes. These plates were then inoculated with the pathogen under sterile conditions using agar discs. Each treatment were replicated three times with PDA without phytoextract serving as the control. All Petri dishes were then incubated at 25±1°C. The radial growth of the fungus was measured after 24, 48, and 72 hours and compared to the control.

The percentage of fungal growth inhibition was calculated using the formula:[18]

$$I = \frac{C-T}{C} \times 100$$

Where,

I = per cent inhibition

C = Colony diameter in control

T = Colony diameter in treatment

3. RESULTS AND DISCUSSION

Among the selected treatments, T_{5}- (Microalgae + FYM + SMC) significantly reduced the disease intensity and increase the plant height (cm), number of leaves and weight of rhizome (g) respectively as compared to other treatments.

3.1 Effect of organic matter and microalgae on disease intensity (%) of turmeric at different DAS

The data provided in Table 1 and Fig. 4 (A) revealed minimum disease intensity in T_{5}- Microalgae @ 1% + FYM @ 1 kg + SMC @ 125 gm (15.05%, 20.96%, 22.92% respectively) followed by T_{3}- SMC @ 250 gm + Microalgae 2% (18.44%, 23.03%, 26.85% respectively), T_{4}- FYM @ 2 kg + Microalgae @ 2% (19.76%, 26.78%, 29.43% respectively), T_{2}- Microalgae @ 4% (21.18%, 27.01%, 30.18% respectively), T_{1}- SMC @ 500 gm (23.29%, 29.38%, 32.90% respectively) T_{6}- FYM @ 4 kg (25.22%, 30.72%, 35.32% respectively) and untreated checked T_{0}- control (27.08%, 32.26%, 38.25% respectively).

Table 1. Effect of organic matter and microalgae on disease intensity (%), plant growth parameters and yield of turmeric

Treatment no.	Name of treatment	Disease intensity (%) @			Plant height(cm) @			No. of leaves/plant @			Rhizome weight(g)
		75DAS	90DAS	105DAS	75DAS	90DAS	120DAS	75DAS	90DAS	120DAS	Mean
T_0	Control	27.08	32.26	38.25	32.00 [c]	33.86	37.53	5.00 [a]	5.53	6.20	22.46
T_1	SMC	23.29	29.38	32.90	47.66 [b]	49.93	53.46	5.53 [b]	6.00	6.60	69.06
T_2	Microalgae	21.18	27.01	30.18	50.26 [b]	52.40	56.06	5.80 [b]	6.20	7.00	97.46
T_3	SMC+Microalgae	18.44 [a]	23.03	26.85	54.00 [a]	55.86	61.33	6.26 [c]	6.60	7.40	123.06
T_4	FYM+microalgae	19.76 [a]	26.78	29.43	51.66 [a]	53.80	58.06	6.00	6.53	7.20	98.66
T_5	Microalgae+FYM+SMC	15.05	20.96	22.92	57.06	59.26	64.53	6.53 [c]	6.93	7.60	188.33
T_6	FYM	25.22	30.72	35.32	33.40 [c]	35.26	39.66	5.20 [a]	5.73	6.40	45.40
	C.D. (5%)	0.89	1.74	1.33	2.71	2.65	1.89	0.33	0.36	0.19	12.34
	SE d±	0.40	0.79	0.60	1.23	1.20	0.86	0.15	0.16	0.08	5.60
	C.V	2.32	3.57	2.40	3.24	3.03	1.98	3.19	3.21	1.54	7.45

** Values in the same column followed by similar letters are non-significantly different from each other at a significance level of P=0.05*

However, at 75 DAS, treatment (T_3, T_4) were found statistically not significantly different from each other. At 90 and 105 DAS all the treatments were found significant over control. The results presented here are consistent with the conclusions drawn by Michalak and Chojnacka [19], who found that microalgae/cyanobacterial cultures, whether in the form of fresh or dry biomass and with or without an appropriate carrier, when applied to the soil, seeds, or foliage, possess antibacterial properties that can effectively assist in managing soil-borne diseases. Similarly, Ida and Istifadah [20] reported that utilizing spent substrate from oyster mushrooms, straw mushrooms, and shiitake led to a decrease in the severity of basal rot disease. Notably, the treatment demonstrating the greatest reduction in disease severity also promoted plant growth.

3.2 Effect of Organic Matter and Microalgae on Plant Growth Parameters of Turmeric

3.2.1 Plant height (cm)

The data provided in Table 1 and Fig. 4 (B) revealed maximum plant height in T_5- Microalgae @ 1% + FYM @ 1 kg + SMC @ 125 gm (57.06 cm, 59.26 cm, 64.53 cm respectively) followed by T_3- SMC @ 250 gm + Microalgae 2% (54.00 cm, 55.86 cm, 61.33 cm respectively), T_4- FYM @ 2 kg + Microalgae @ 2% (51.66 cm, 53.80 cm, 58.06 cm respectively), T_2- Microalgae @ 4% (50.26 cm, 52.40 cm, 56.06 cm respectively), T_1- SMC @ 500 gm (47.66 cm, 49.93 cm, 53.46 cm respectively) T_6- FYM @ 4 kg (33.40 cm, 35.26 cm, 39.66 cm respectively) and untreated checked T_0- control (32.00 cm, 33.86 cm, 37.53 cm respectively). However, at 75 DAS, treatment (T_3, T_4); (T_4, T_2); (T_2, T_1) and (T_6, T_0) were found statistically not significantly different from each other. At 90 and 105 DAS all the treatments were found significant over control.

3.2.2 Average number of leaves/plant

The data depicted in Table 1 and Fig. 4 (C) reveals that the total number of leaves significantly increased in T_5- Microalgae @ 1% + FYM @ 1 kg + SMC @ 125 gm (6.53%, 6.93% 7.60% respectively) followed by T_3- SMC @ 250 gm + Microalgae 2% (6.26%, 6.60%, 7.40% respectively), T_4- FYM @ 2 kg + Microalgae @ 2% (6.00%, 6.53%, 7.20% respectively), T_2- Microalgae @ 4% (5.80%, 6.20%, 7.00% respectively), T_1- SMC @ 500 gm (5.53%, 6.00%, 6.60% respectively) T_6- FYM @ 4 kg (5.20%, 5.73%, 6.40% respectively) and untreated checked T_0- control (5.00%, 5.53%, 6.20% respectively). However, at 75 DAS, treatment, (T_5, T_3); (T_3, T_4); (T_4, T_2); (T_2, T_1) and (T_6, T_0) were found statistically not significantly different from each other. At 90 and 105 DAS, all the treatments were found significant over control.

The results presented above align with the findings of Dineshkumar et.al. [21], who investigated the effectiveness of microalgae as biofertilizers for onion plants. In their study, dry biomass from microalgae such as *Chlorella vulgaris* and *Spirulina platensis* combined with cow dung applied to the soil as separate treatments revealed significant improvements in growth parameters, yield attributes, biochemical composition, anti-nutritional composition, and mineral content as compared to other treatment groups.

3.3 Effect of Organic Matter and Microalgae on Yield of Turmeric

3.3.1 Weight of rhizome

The data depicted in the Table 1 and Fig. 4 (D) reveals that the rhizome weight of turmeric significantly increased in T_5- Microalgae @ 1% + FYM @ 1 kg + SMC @ 125 gm (188.33g) followed by T_3- SMC @ 250 gm + Microalgae 2% (123.06 g), T_4- FYM @ 2 kg + Microalgae @ 2% (98.66g), T_2- Microalgae @ 4% (97.46 g), T_1- SMC @ 500 gm (69.06 g) T_6- FYM @ 4 kg (45.40 g) and untreated checked T_0- control (22.46 g). However, all the treatments were found significant over control. The results are in lines with the findings presented by Kumar et.al.[22] where they observed the effectiveness of microalgae combined with cow dung enhances the improvement in yield attributes. Similarly, the results align with those of Wasnikar et al. [23], who investigated the impact of spent mushroom substrate and various combinations thereof on disease incidence, severity index, and phenotypic parameters found that the utilization of button spent mushroom substrate at different concentrations mixed with soil mitigate disease and increased in yield as well.

Table 2. *In vitro* effects of botanicals at different conc. on radial growth (mm) of *Fusarium equiseti* after 24 hrs, 48 hrs, and 72 hrs

Treatment no.	Treatment	Average radial growth of mycelium (10% conc.) @			% growth inhibition (10%conc.) @			Average radial growth of mycelium (30% conc.) @			% growth inhibition (30%conc.) @		
		24hrs	48hrs	72hrs	24hrs	48hrs	72hrs	24hrs	48hrs	72hrs	24hrs	48hrs	72hrs
T0	Control	5.66	9.83	16.33	0.00	0.00	0.00	6.16	10.83	17.00	0.00	0.00	0.00
T1	*Zanthoxylum acanthopodium*	2.16	2.66	3.66	61.76	72.87	77.54	1.16	1.66	2.33	81.07	84.61	86.27
T2	*Phlogacanthus thyrsiformis*	2.83	4.33	5.33	50.00	55.93	67.34	1.33	2.33	3.83	78.38	78.46	77.45
T3	*Solanum xanthocarpum*	3.33	4.83	5.83	41.18	50.84	64.28	1.83	2.83	4.16	70.27	73.84	75.48
T4	*Centella asiatica*	4.83	6.16	7.83	14.71	37.28	52.04	3.83	5.33	7.16	37.84	50.77	57.84
T5	*Drymaria cordata*	4.50	5.50	7.00	20.59	44.06	57.14	2.83	4.16	5.83	54.06	61.53	65.68
T6	*Persicaria chinensis*	3.83	5.33	6.33	32.36	45.76	61.22	2.33	3.83	5.33	62.16	64.61	68.62
T7	*Gynura cusimbua*	4.66	5.83	7.66	17.64	40.67	53.05	3.66	5.16	6.33	40.53	52.30	62.74
	C.D. (5%)	0.49	0.84	1.61				0.87	1.54	1.00			
	C.V.	6.99	8.63	12.17				17.11	19.32	8.70			

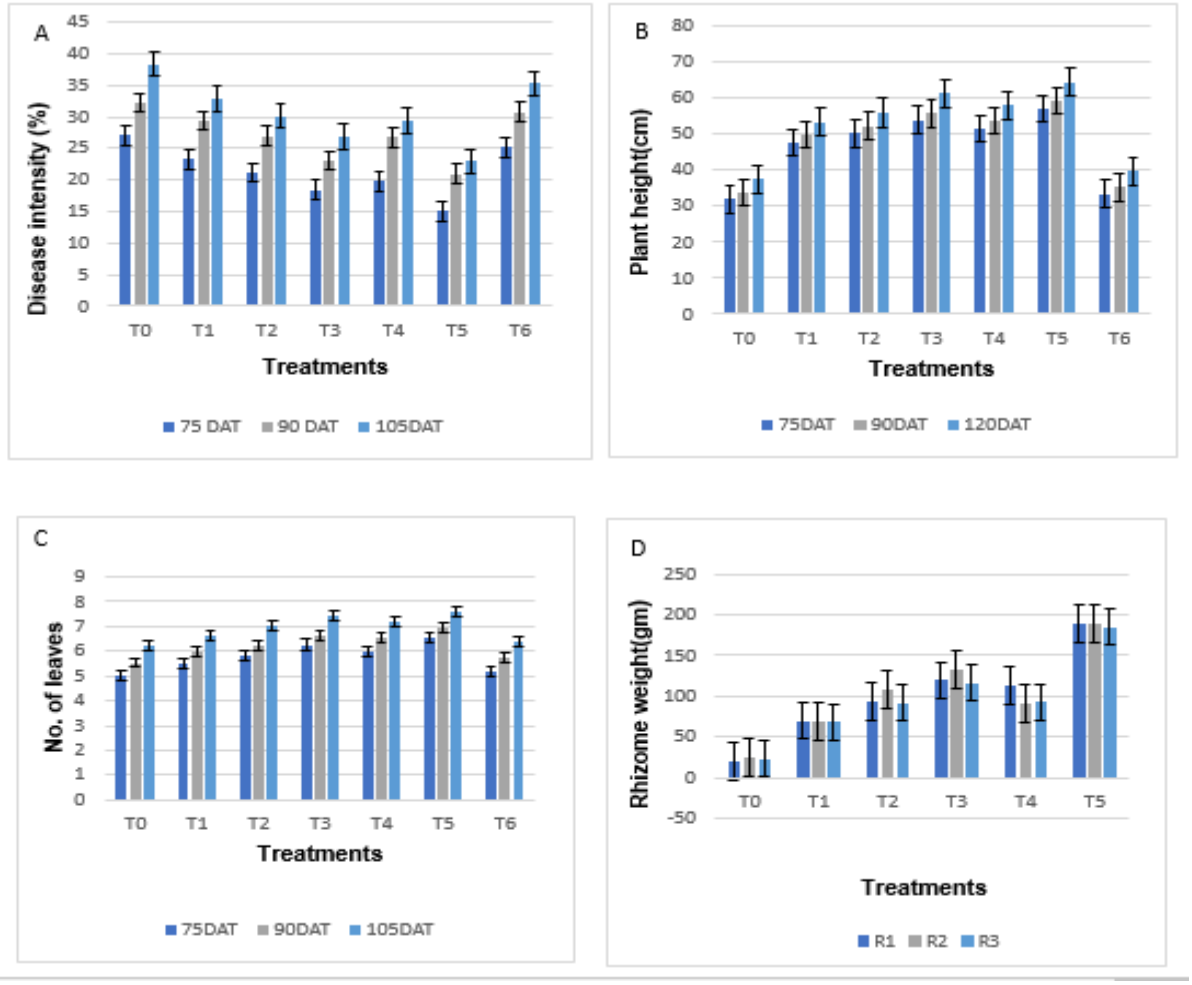

Fig. 4. Effect of organic matter and microalgae on disease intensity (%), plant growth parameters and yield of turmeric. A- disease intensity (±SE%) where SE is standard Error; B- Plant height (cm); C- No. of leaves; D- Rhizome weight (g).

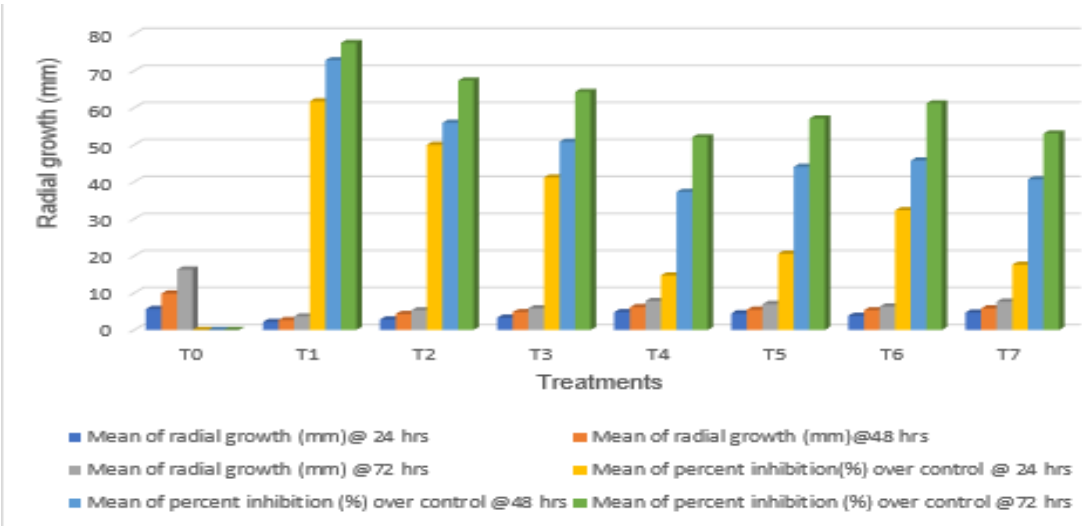

Fig. 5. Effect of botanicals at a concentration of 10% on the radial growth (mm) of *Fusarium equiseti in vitro* after 24 hours, 48 hours, and 72 hours.

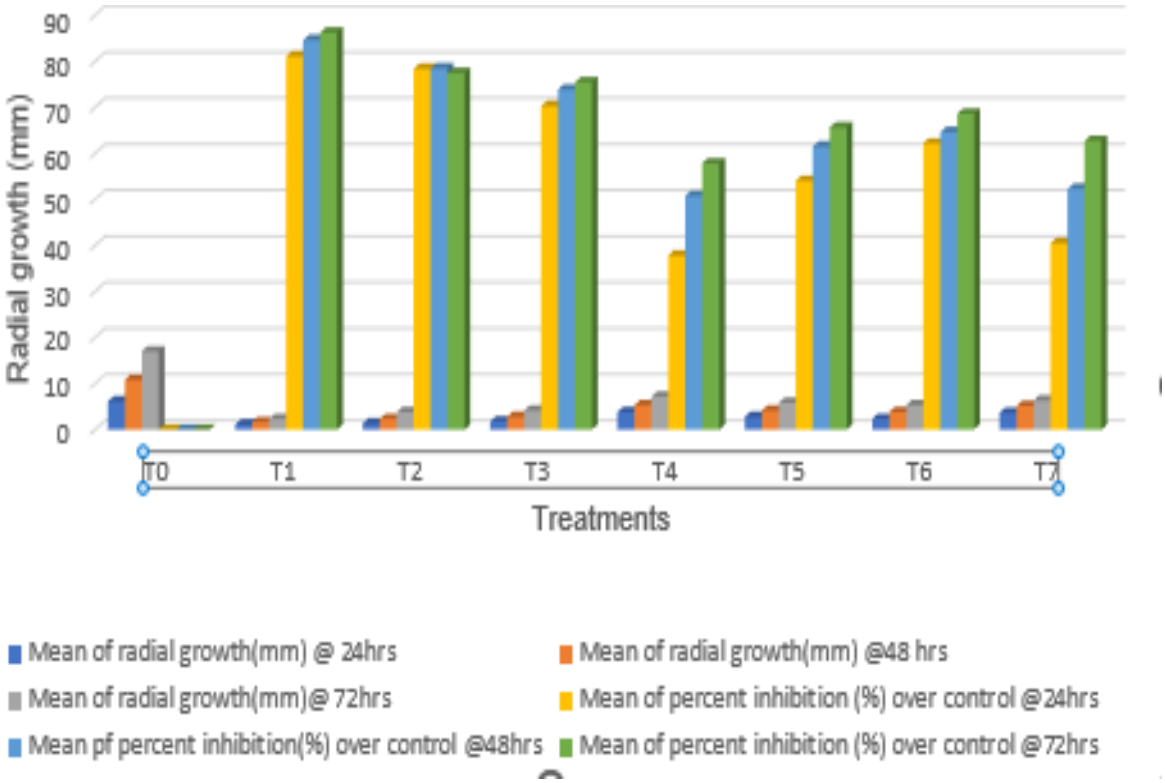

Fig. 6. Effect of botanicals at a concentration of 30% on the radial growth (mm) of *Fusarium equiseti in vitro* after 24 hours, 48 hours, and 72 hours

3.4 Evaluation of Botanicals against *Fusarium equiseti in vitro*

The botanicals extracts were screened for their efficacy against *Fusarium equiseti* on PDA amended with their 10% and 30% concentration. The data on the radial growth of the colony (mm) and percent inhibition of mycelial growth recorded has been presented here. The data presented in Table 2 reveals that at 10% concentration, after 24 hrs, 48 hrs and 72 hrs incubation, the least radial growth of *Fusarium equiseti* was observed in T_1-*Xanthoxylum acanthopodium* (3.66 mm), followed by T_2-*Phlogacanthus thyrsiformis* (5.33 mm), T_3-*Solanum xanthocarpum* (5.83 mm), T_6-*Persicaria chinensis* (6.33 mm), T_5- *Drymaria cordata* (7.00 mm), T_7- *Gynura cusimbua* (7.66 mm), T_4 *Centella asiatica* (7.83 mm) and T_0-Untreated (12.66 mm). All the botanical treatments exhibited significance over control. The result showed that maximum percentage of inhibition was observed in T_1-*Xanthoxylum acanthopodium* (77.54%), followed by T_2-*Phlogacanthus thyrsiformis* (67.34%), T_3-*Solanum xanthocarpum* (64.28%), T_6- *Persicaria chinensis* (61.22%), T_5- *Drymaria cordata* (57.14%), T_7- *Gynura cusimbua* (53.05%), T_4 *Centella asiatica* (52.04%) and T_0-Untreated (0.00%).

At 30% concentration, after 24 hrs, 48 hrs and 72 hrs incubation, the least radial growth of *Fusarium equiseti* was observed in T_1-*Xanthoxylum acanthopodium* (2.33 mm), followed by T_2- *Phlogacanthus thyrsiformis* (3.83 mm), T_3- *Solanum xanthocarpum* (4.16 mm), T_6-*Persicaria chinensis* (5.33 mm), T_5- *Drymaria cordata* (5.83 mm), T_7- *Gynura cusimbua* (6.33 mm), T_4 *Centella asiatica* (7.16 mm) and T_0-Untreated (17.00 mm). All the botanical treatments exhibited significance over control. The result showed that maximum percentage of inhibition was observed in T_1-*Xanthoxylum acanthopodium* (86.27%), followed by T_2-*Phlogacanthus thyrsiformis* (77.45%), T_3-*Solanum xanthocarpum* (75.48%), T_6- *Persicaria chinensis* (68.62%), T_5- *Drymaria cordata* (65.68%), T_7- *Gynura cusimbua* (62.74%), T_4 *Centella asiatica* (57.84%) T_0-Untreated (0.00%).

In concurrence with the current results, similar results were earlier recorded by David et.al. [13]

who conducted *in vitro* screening of indigenous botanicals and examined the anti-fungal properties against *Helminthosporium oryzae.* The efficacy of standard botanical extracts at various concentrations (10%, 15%, and 20%) against the fungus's growth were assessed in both liquid and solid culture media. In the solid media test, the highest percentage inhibition of radial growth was observed at a concentration of 20% in *S. incanum* followed by *A. hookerii, M. pachycarpa*, *M. benghalensis* and *F. thyrsiflorus* when compared to the untreated control.

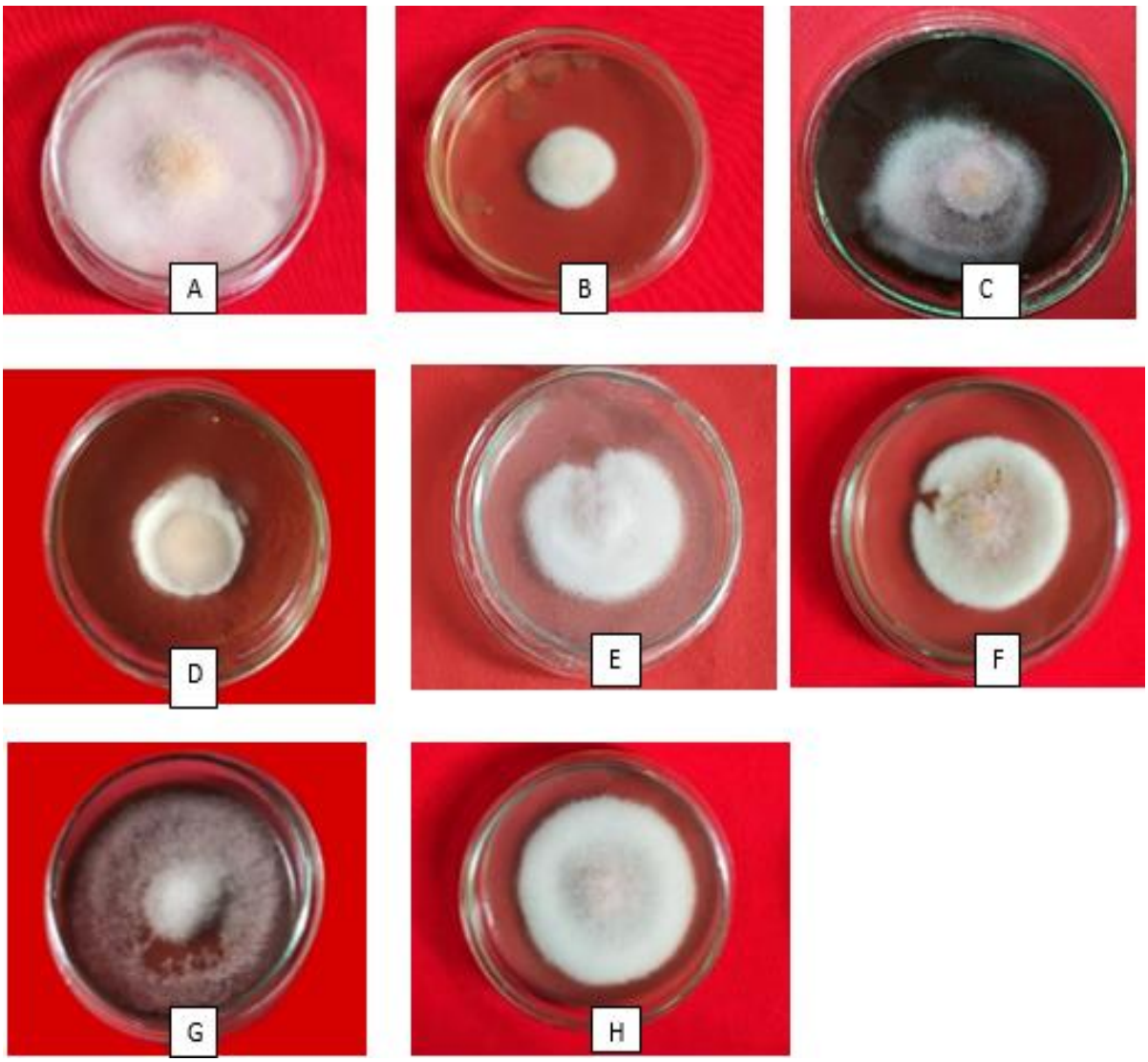

Fig. 7. *In vitro* evaluation of botanicals on radial growth (mm) of *Fusarium equiseti* at 10% concentration

A- T_0 – Control; B- T_1– Zanthoxylum acanthopodium; C- T_2 – Phlogacanthus thyrsiformis; D- T_3 - Solanum xanthocarpum; E- T_6 – Persicaria chinensis; F- T_5 – Drymaria cordata; G- T_7 – Gynura cusimbua; H- T_4 – Centella asiatica

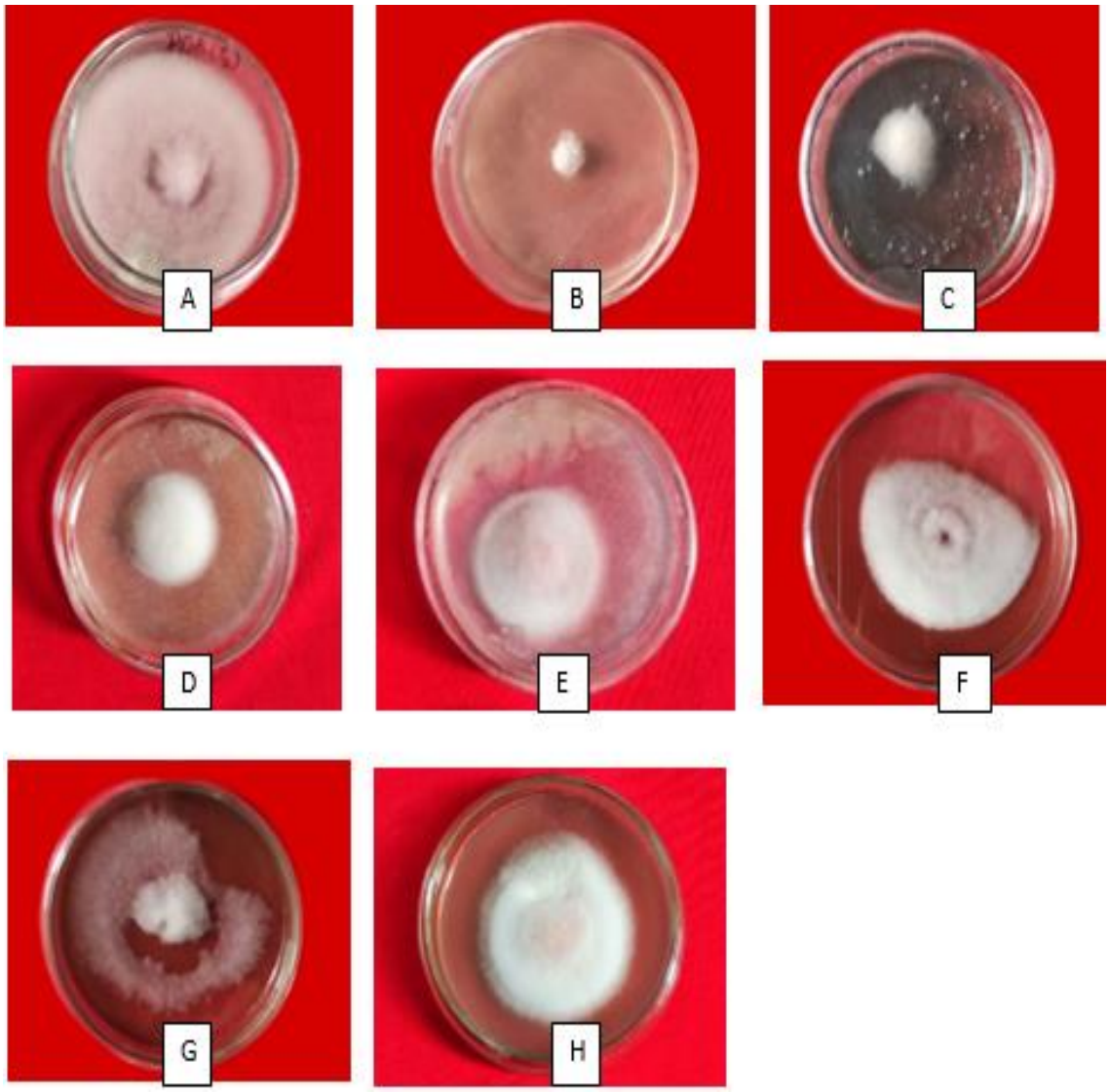

Fig. 8. In vitro evaluation of botanicals on radial growth (mm) of Fusarium equiseti at 30% concentration

A- T0 – Control; B- T1– Zanthoxylum acanthopodium; C- T2 – Phlogacanthus thyrsiformis; D- T3 - Solanum xanthocarpum; E- T6 – Persicaria chinensis; F- T5 – Drymaria cordata; G- T7 – Gynura cusimbua; H- T4 – Centella asiatica

4. CONCLUSION

The present study clearly reveals that among the selected treatments, T_5 (Microalgae + FYM + SMC) significantly reduced the disease intensity of *Fusarium equiseti*, increased plant height, number of leaves and rhizome weight. The evaluation of botanicals against *Fusarium equiseti* in *in vitro* at concentrations of 10% and 30% revealed effectiveness particularly in T_1, involving *Xanthoxylum acanthopodium*. This shows the ecofriendly application of bio-fertilizers in safeguarding plant health. Hence, the utilization of organic enhancements and biocontrol agents can be cost-effective, sustainable, and devoid of residual side effects. Consequently, these environmentally friendly treatments emerge as superior alternatives to fungicides, given their minimal adverse effects on the ecosystem, easy accessibility, and economic feasibility. Research on the effects of *Bacillus subtilis*, soil amendments, and microalgae treatments on *Fusarium equiseti* in turmeric cultivation presents promising potential. This encompasses optimizing treatment combinations and formulating biocontrol solutions that incorporate these components to effectively manage *Fusarium equiseti* and other soil-borne

pathogens in turmeric farming. Evaluating the impact of these treatments on soil health parameters, including microbial diversity, soil structure, and nutrient availability, as well as on turmeric quality attributes such as curcumin content, rhizome yield, and disease resistance, is essential. By addressing these research areas, significant advancements can be made towards developing sustainable, environmentally friendly, and efficient strategies for controlling *Fusarium equiseti* and improving turmeric production and resilience.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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