



RESEARCH ARTICLE

Comparative *in vitro* efficacy of biological agents, plant extracts and novel fungicides for controlling seed-borne pathogens in cucumber (*Cucumis sativus* L.)

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Abstract

Cucumber (*Cucumis sativus*) belongs to the family Cucurbitaceae. Cucumbers are an important part of human diets as they contain essential vitamins, minerals and antioxidants. They are among the most significant commercial crops and are vital to the overall livelihood and food security of the people. They are well known for alleviating constipation, lowering blood sugar levels and treating jaundice, among health benefits. Cucumbers, however, are highly susceptible to attacks from various seed-borne pathogens. Seed-borne fungi such as *Aspergillus niger* (ITCC I.D. No. 11966.23) and *A. flavus* were identified from cucumber seeds through pathogenicity tests and cultural as well as morphological characterization. Among the ten fungicides tested, chlorothalonil exhibited the highest inhibition (100 %) *A. niger*, while Propiconazole was the most effective against *A. flavus* (100 %). Three bioagents were also evaluated, with *Trichoderma harzianum* showing the highest inhibition (64.52 %) for *A. niger*, while *Pseudomonas fluorescens* exhibited highest inhibition (53.74 %) for *A. flavus*. Eleven botanicals at 20 % concentration were tested and *Allium sativum* (garlic) demonstrated complete inhibition (100 %) against both *A. niger* and *A. flavus*. In growth promotion studies, it was observed that the pure culture of *T. asperellum*, when applied to cucumber seeds, resulted in the highest germination percentage (93.02 %), with greatest shoot length (18.59 cm) and the longest root length (6.67 cm). Overall, the study demonstrates that *T. asperellum*, *A. sativum* extract and selected fungicides can effectively manage seed-borne *Aspergillus* spp. while promoting cucumber seedling growth, highlighting their potential for integrated disease management strategies.

Keywords: *Aspergillus* spp.; bioagents; botanicals; cucumber; fungicides; seed-borne pathogens

Introduction

Cucumber (*Cucumis sativus* L.), a member of the Cucurbitaceae family, is among the most widely cultivated vegetable crops globally, valued for its economic and nutritional importance (1). Originating from India, cucumber cultivation plays a vital role in supporting vegetable-based livelihoods, but its often constrained by seed-borne fungal pathogens. Globally, cucumber ranks among the top three vegetable crops in production, with China and India serving as major producers. However, overall productivity is frequently reduced due to seed-borne fungal infections that impair seed germination and seedling vigor. Raw cucumber fruit with peel contains approximately 95 % water and provides 16 kcal of energy, 0.65 g of protein, 3.63 g of carbohydrates and 16.4 g of vitamin K per 100 g. It contains low concentrations of nutrients and essential minerals but remains a valuable dietary component due to its hydrating and antioxidant properties. Tetracyclic triterpenes, chemically known as cucurbitacin, are the bitter compounds responsible for cucumber's distinctive flavor.

In terms of cultivated area (12.58 lakh ha) and production output (703.38 lakh tons), China leads global cucumber production, followed by the Russian Federation, which has an area of 40851 ha and produce roughly 16.26 lakh tons (2). In India, cucumber is cultivated on approximately 1.05 lakh ha, yielding about 1588 thousand MT annually (3).

The primary group of pathogens responsible for reducing seed germination is seed-borne fungi. Pre-emergence damping-off, seedling blight and diseased seedlings are the main causes of damage, typically occurring during the seed germination phase. When germination begins, dormant fungal spores within the seed become active, leading to seed mortality and weak seedling development. certain fungi may even destroy the seeds prior to germination, often while they are still attached to the mother plant. The pathogen likely releases toxic metabolites that impair seed germination potential. Diseases caused by *A. niger*, particularly seed and seedling rot, have been reported in several fields, although detailed studies in India, remain limited. The pathogen is known to be predominant both in seeds and soil.

Chemical-based control methods often leave behind pesticide residues, disrupt the balance of soil microflora and pose environmental and public health concerns (4). Although fungicides remain widely used, their prolonged and excessive application can result in environmental contamination and microbial imbalance. Hence, biological control using antagonistic microorganisms such as *Trichoderma* spp., *P. fluorescens* and *Bacillus subtilis* has emerged as an eco-friendly alternative for managing seed- and soil-borne diseases (5, 6). Among the bio-control agents, *Trichoderma* spp. are well recognized for their antagonistic activity against several soil- and seed-borne pathogens. Their rapid growth, adaptability to diverse environments and production of antifungal metabolites make them a reliable component of sustainable disease management programs (7-9).

Plant extracts containing bioactive compounds such as phenolics, terpenoids and alkaloids, have also been reported to suppress pathogenic fungi and enhance host defense mechanisms. Their application offers a promising, eco-friendly alternative for managing seed-borne infections (10). Despite the widespread use of fungicides, the occurrence of seed-borne *Aspergillus* spp. in cucumber remains a major constraint to seed germination and vigor. Therefore, the present study was conducted to compare the *in vitro* efficacy of selected fungicides, bioagents and botanicals against *A. niger* and *A. flavus* isolated from cucumber seeds and to evaluate their effects on seed germination and seedling growth.

Materials and Methods

Location

The present experiment was conducted in the Department of Plant Pathology, College of Agriculture, OUAT, Bhubaneswar, during 2023, to isolate, purify and identify the pathogens associated with cucumber seeds. This experiment aimed to evaluate the efficacy of different fungicides, bioagents and botanicals against causal organisms.

Experimental details

A completely randomized design (CRD) was followed to conduct the experiments, with three replications. The percent inhibition of the test pathogen was calculated using the formula (11).

$$\text{Percent inhibition (I)} = \frac{(C-T)}{C} \times 100$$

where,

C = growth of test fungus (mm) in control plates

T = growth of fungus (mm) in treatment plates

Pathogenicity test

The test was carried out following two methods. The first was the seed inoculation method, in which surface-sterilized cucumber seeds were rolled over a seven-day-old pure culture plates of the test fungi. The inoculated seeds were then placed on moist blotter paper and incubated at 28 ± 1 °C for seven days. The second was the seedling inoculation method, in which ten-day-old cucumber seedlings were inoculated with the prepared pathogen suspension using the pinprick method.

In vitro evaluation of fungicides against test fungus

The efficacy of selected fungicides was evaluated against the pathogens isolated from cucumber seeds using the poisoned food technique with potato dextrose agar (PDA) as the basal medium. The fungicides tested include: propiconazole 25 % EC, tebuconazole 50 % + trifloxystrobin 25 % WG, carbendazim 12 % + mancozeb 63 %, chlorothalonil 75 % WP, tebuconazole 25.9 % EC, thiophanate-methyl 50 % WP, hexaconazole 5 % SC, difenoconazole 10 % WP, carboxin 37.5 % + thiram 37.5 % and azoxystrobin 25 % EC. The experiment involved dispensing the poisoned medium equally into Petri plates, with three replications for each treatment. Active growing test fungi were used to obtain 5 mm discs from the periphery, which were then transferred to the center of plates containing the poisoned medium. A control set was maintained by placing fungal discs on untreated PDA medium. All plates were incubated at 28 ± 2 °C in a BOD incubator until the control plates showed full mycelial growth. The diameter of the fungal colonies in the treatment plates was measured and compared with that of the control to determine the percent inhibition.

In vitro evaluation of botanicals against test fungus

The efficacy of selected plant extracts (botanicals) was evaluated against the test pathogens isolated from cucumber seeds. The plant extracts used included garlic (*Allium sativum*), neem (*Azadirachta indica*), giloy (*Tinospora cordifolia*), karanj (*Pongamia pinnata*), turmeric (*Curcuma longa*), ginger (*Zingiber officinale*), onion (*Allium cepa*), custard apple (*Annona squamosa*), eucalyptus (*Eucalyptus* spp.), lantana (*Lantana camara*) and marigold (*Tagetes* spp.) were used. In the experiment, 100 g of fresh plant material were crushed in 100 mL of sterile distilled water using a blender. For preparing a 20 % (v/v or w/v) working solution, 20 mL (or 20 g) of the stock or solid extract was mixed with 80 mL (or 80 g) of solvent (usually sterile distilled water) to obtain a 100 mL final solution. The measured botanical extract was added to molten, sterilized PDA medium just before pouring, ensuring thorough mixing for uniform distribution. The medium was poured into sterile Petri dishes and allowed to solidify, after which it was inoculate with the test fungal pathogen under aseptic conditions. Each plant extract treatment was replicated three times. After the medium solidified, 5 mm mycelial discs from a seven-day-old culture of the test pathogen were placed at the center of each plate under aseptic conditions. Control plates contained only PDA medium without any plant extract. All plates were incubated at 27 ± 1 °C for seven days and fungal colony diameter was measured to determine the percentage inhibition of growth.

In vitro evaluation of bioagents against test fungus

The efficacy of selected biocontrol agents was evaluated against the test pathogens isolated from cucumber seeds. The biocontrol agents used were *T. asperellum*, *P. fluorescens* and *T. harzianum*. The evaluation was performed using the dual-culture technique (12). A 5 mm discs containing the test pathogen and the respective bio-agents were cut from actively growing cultures and placed equidistant from each other on solidified PDA medium in Petri plates under aseptic conditions. The plates were incubated at 27 ± 1 °C for seven days. Control plates contained only the test fungal disc, serving as untreated controls. The antagonistic activity of bioagents was measured based on radial growth inhibition of the pathogen compared to the control.

Growth promotion studies using bioagents and fungicides

Seed treatments are described as follows:

T1-seed treatment with grain formulation of *T. asperellum* at 10 g kg⁻¹

T2- seed treatment with pure culture of *T. asperellum* at 3 g kg⁻¹

T3-seed treatment with *P. fluorescens* at 10 g kg⁻¹

T4-seed treatment with carbendazim at 1 g kg⁻¹

T5-seed treatment with chlorothalonil 1 g kg⁻¹

T6- untreated control

Experimental details

The experiment was conducted following a randomized block design (RBD) consisting of six treatments and two replications, making a total of twelve experimental units. Observations were recorded for germination percentage, shoot length and root length after the germination of cucumber seeds. The germination percentage (GP) for each treatment was calculated using the formula:

$$GP = \frac{\text{Seeds germinated}}{\text{Total seeds}} \times 100$$

This design helps to evaluate the effects of different treatments while minimizing the variation due to environmental factors between blocks.

Table 1. *In vitro* evaluation of fungicides against *Aspergillus niger* and *Aspergillus flavus*

Tr. no.	Treatments	<i>Aspergillus niger</i>		<i>Aspergillus flavus</i>	
		Colony diameter (mm)*	Inhibition (%)	Colony diameter (mm)	Inhibition (%)
T1	Chlorothalonil	0.00	100 (90.00)**	0.00	100 (90.00)
T2	Propiconazole	5.71	93.65 (75.40)	0.00	100 (90.00)
T3	Azoxystrobin	88.8	1.33 (6.62)	59.73	32.80 (34.94)
T4	Tebuconazole	0.00	100 (90.00)	7.15	91.95 (73.51)
T5	Carbendazim 12 % + mancozeb 63 %	0.00	100 (90.00)	5.37	93.95 (75.76)
T6	Tebuconazole 50 % + trifloxystrobin 25 %	5.38	94.01 (75.83)	0.00	100 (90.00)
T7	Thiophanate methyl	7.83	91.29 (72.83)	0.00	100 (90.00)
T8	Carboxin 37.5 % + thiram 37.5 %	8.69	90.33 (71.88)	8.6	90.32 (71.87)
T9	Difenoconazole	9.43	89.51 (71.10)	10.67	87.98 (69.71)
T10	Hexaconazole	6.98	92.23 (73.81)	0.00	100 (90.00)
T11	Control (untreated)	90.00	0.00 (0.00)	88.9	0.00 (0.00)
	SE(m)	0.53	0.59	0.21	0.24
	CD 5 %	1.57	1.74	0.61	0.69
	CV	4.58 %	1.33 %	2.20 %	0.5 %

*Average of three replications. **Figures in parentheses are arc sin transformation values.

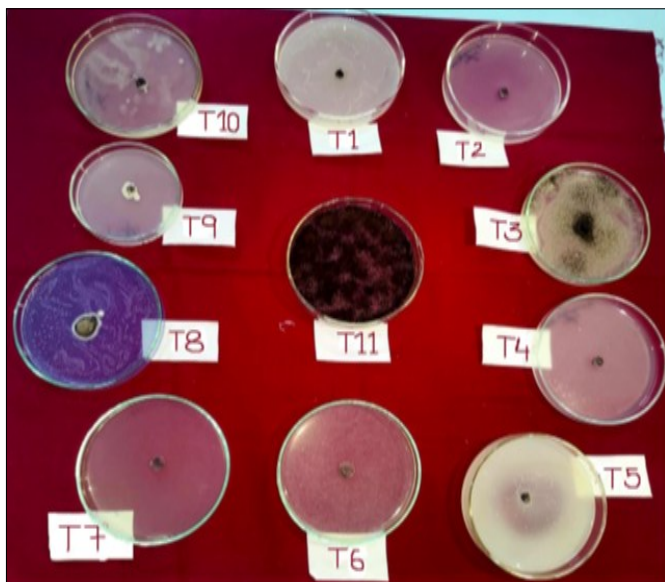


Fig. 1(a). *In vitro* evaluation of fungicides against *Aspergillus niger*.

Statistical analysis

The data from various treatments were analyzed statistically using Microsoft Excel with an add-in like analyse-it or XLSTAT. When treatment effects were found to be statistically significant, the standard error (S.E.) and critical difference (C.D.) were calculated at a 5 % significance level.

Results

In vitro evaluation of fungicides

Ten fungicides were tested *in vitro* against *A. niger* and *A. flavus* (Table 1; Fig. 1a, b). *A. niger* showed no growth when treated with chlorothalonil (0.00 mm), carbendazim 12 % + mancozeb 63 % (0.00 mm) and tebuconazole (0.00 mm), indicating complete inhibition of fungal growth. In contrast, azoxystrobin (88.8 mm), difenoconazole (9.43 mm) and carboxin 37.5 % + thiram 37.5 % (8.69 mm) were the least effective, as compared to the untreated control which showed a full mycelial growth of 90 mm. Similarly, *A. flavus* exhibited no growth in the presence of chlorothalonil (0.00 mm), propiconazole (0.00 mm), tebuconazole 50 % + trifloxystrobin 25 % (0.00 mm), thiophanate methyl (0.00 mm) and hexaconazole (0.00 mm). However, azoxystrobin (59.73 mm), difenoconazole (10.67 mm) and carboxin 37.5 % + thiram 37.5 % (8.6 mm) were relatively less effective compared to the untreated control, which recorded 88.9 mm of mycelial growth.

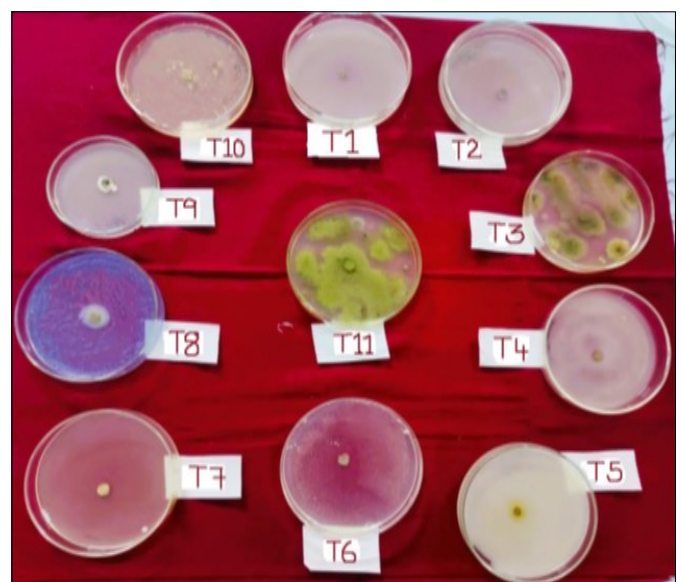


Fig. 1(b). *In vitro* evaluation of fungicides against *Aspergillus flavus*.

In vitro evaluation of phytoextracts/botanicals

Eleven botanicals, each tested at a 20 % concentration, were evaluated *in vitro* against *A. niger* and *A. flavus* (Table 2; Fig. 2a, b). For both *A. niger* and *A. flavus*, garlic showed complete inhibition of mycelial growth (0.00 mm) and the highest mycelial growth inhibition (100 %) at 20 % concentration. For *A. niger*, neem (88.80 mm), marigold (88.03 mm) and custard apple (86.47 mm) exhibited the least inhibition, compared with the untreated control, which recorded 90.00 mm of mycelial growth at 20 % concentration. Similarly, for *A. flavus*, custard apple (85.25 mm), lantana (83.01 mm) and marigold (82.83 mm) showed lower inhibitory effects compared to the untreated control, which recorded 89.73 mm of mycelial growth at 20 % concentration.

In vitro evaluation of bioagents

Three biocontrol agents, each were evaluated *in vitro* against *A. niger* and *A. flavus* (Table 3, Fig. 3 a, b). Among the three antagonists tested, *T. harzianum* was the most effective, showing the lowest linear mycelial growth of (31.5 mm) against *A. niger*, resulting in the highest mycelial inhibition (64.6 %), whereas *T. asperellum* (56.33 mm) was the least effective against, compared to the untreated control (89.00). Similarly, *P. fluorescens* was the most effective against *A. flavus*, recording the lowest linear mycelial growth (41.1 mm) and the highest mycelial growth

inhibition (53.8 %), whereas *T. harzianum* (43.73 mm) was the least effective, compared to the untreated control (89.00 mm).

Growth promotion studies using bioagents and fungicides

Among the various treatments, germination percentages ranged from 72.27 % to 93.02 %. The highest germination rate was observed with seed treatment using the pure culture of *T. asperellum* (93.02 %), followed by seed treatment with the grain formulation of *T. asperellum* (91.10 %) (Table 4). Seed treated with *P. fluorescens* resulted in a germination rate of 90.86 %, while treatments with chlorothalonil and carbendazim showed germination rates of 84.62 % and 83.11 %, respectively. All these treatments recorded higher germination percentages compared to the untreated control (72.27 %).

The shoot length of the seedlings ranged from 14.81 cm to 18.59 cm. The greatest shoot length was observed in seedlings from seeds treated with the pure culture of *T. asperellum* (18.59 cm), followed by those treated with the grain formulation of *T. asperellum* (16.44 cm). Seeds treated with *P. fluorescens* resulted in a shoot length of 15.81 cm, while treatments with chlorothalonil and carbendazim produced shoot lengths of 15.78 cm and 15.67 cm, respectively. All these treatments showed longer shoot growth compared to the untreated control (14.81 cm).

Table 2. *In vitro* evaluation of botanicals at 20 % against *Aspergillus niger* and *Aspergillus flavus*

Tr. no.	Treatments	<i>Aspergillus niger</i>		<i>Aspergillus flavus</i>	
		Radial growth (mm)*	Inhibition (%)	Radial growth (mm)	Inhibition (%)
T1	<i>Allium sativum</i> (garlic)	0.00	100 (90.00)**	0.00	100 (90.00)
T2	<i>Eucalyptus</i> sp. (Eucalyptus)	20.73	79.96 (61.31)	21.45	76.08 (60.71)
T3	<i>Curcuma longa</i> (turmeric)	60.57	32.7 (34.87)	50.84	43.33 (41.16)
T4	<i>Zingiber officinale</i> (ginger)	64.33	28.52 (32.27)	73.67	17.89 (25.02)
T5	<i>Allium cepa</i> (onion)	71.23	20.85 (27.16)	75.47	15.89 (23.49)
T6	<i>Pongamia pinnata</i> (karanj)	40.40	55.11 (47.93)	60.39	32.69 (34.87)
T7	<i>Tinospora cordifolia</i> (giloy)	70.53	21.63 (27.17)	76.01	15.29 (23.01)
T8	<i>Lantana camara</i> (lantana)	73.17	18.7 (25.62)	83.01	7.49 (15.88)
T9	<i>Annona squamosa</i> (custard apple)	86.47	3.92 (11.42)	85.25	4.99 (12.90)
T10	<i>Azadirachta indica</i> (neem)	88.80	1.33 (6.62)	58.47	34.83 (36.16)
T11	<i>Tagetes</i> sp. (marigold)	88.03	2.18 (8.94)	82.83	7.68 (16.08)
T12	Control (untreated)	90.00	0.00 (0.00)	89.73	0.00 (0.00)
	SE (m)	0.44	0.48	0.51	0.57
	CD 5 %	1.27	1.41	1.50	1.67
	CV	1.20 %	2.78 %	1.41 %	3.35 %

*Average of three replications. **Figures in parentheses are arc sin transformation values.

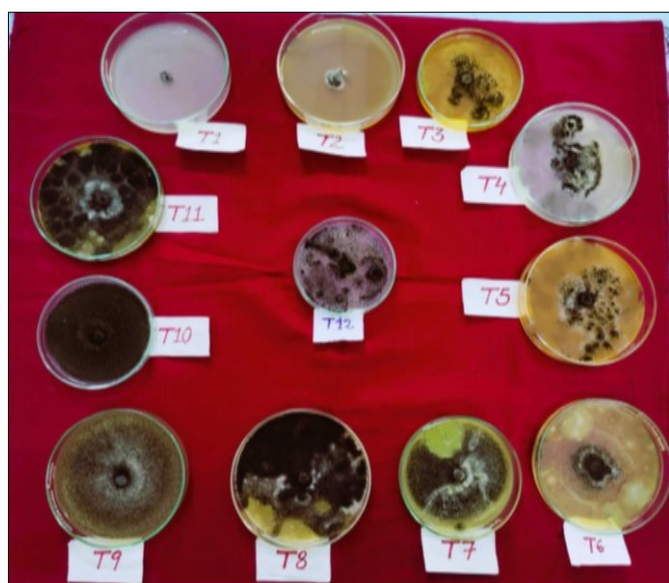


Fig. 2(a). *In vitro* evaluation of botanicals at 20 % concentration against *Aspergillus niger*.

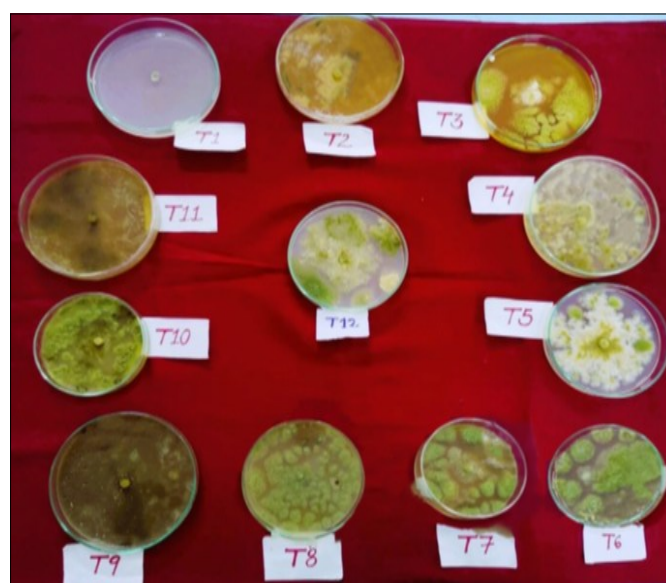


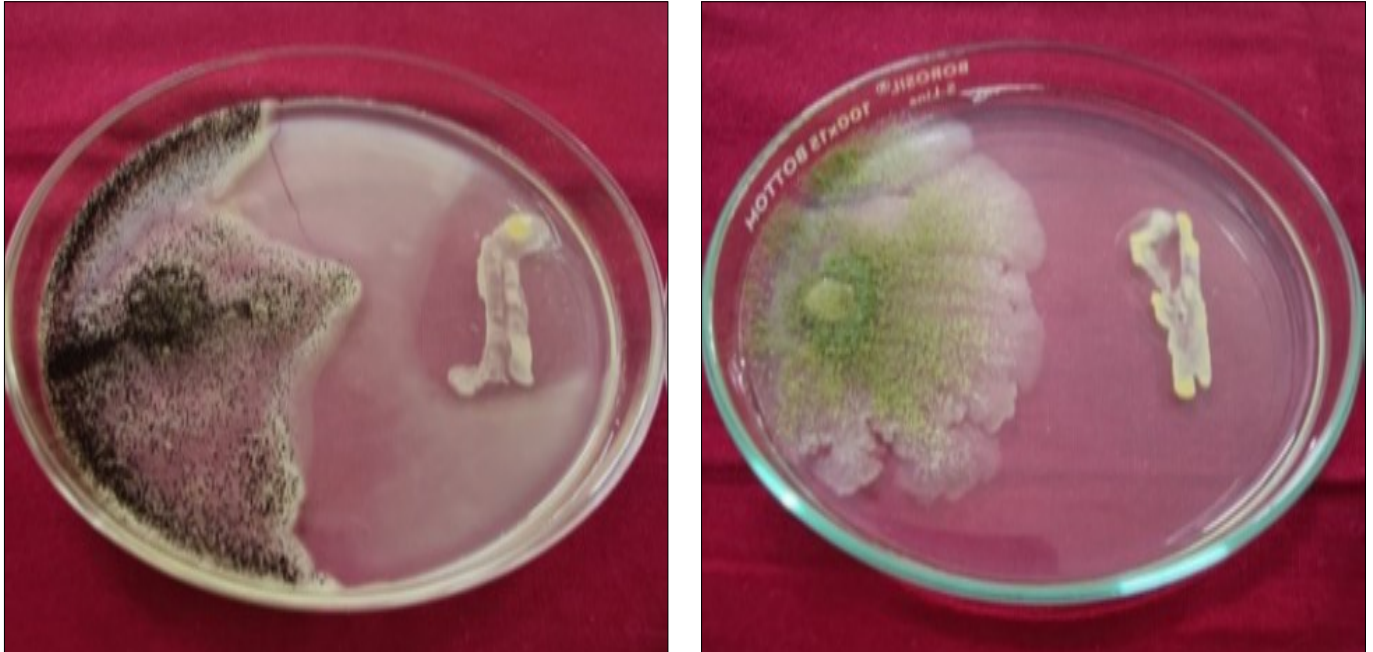
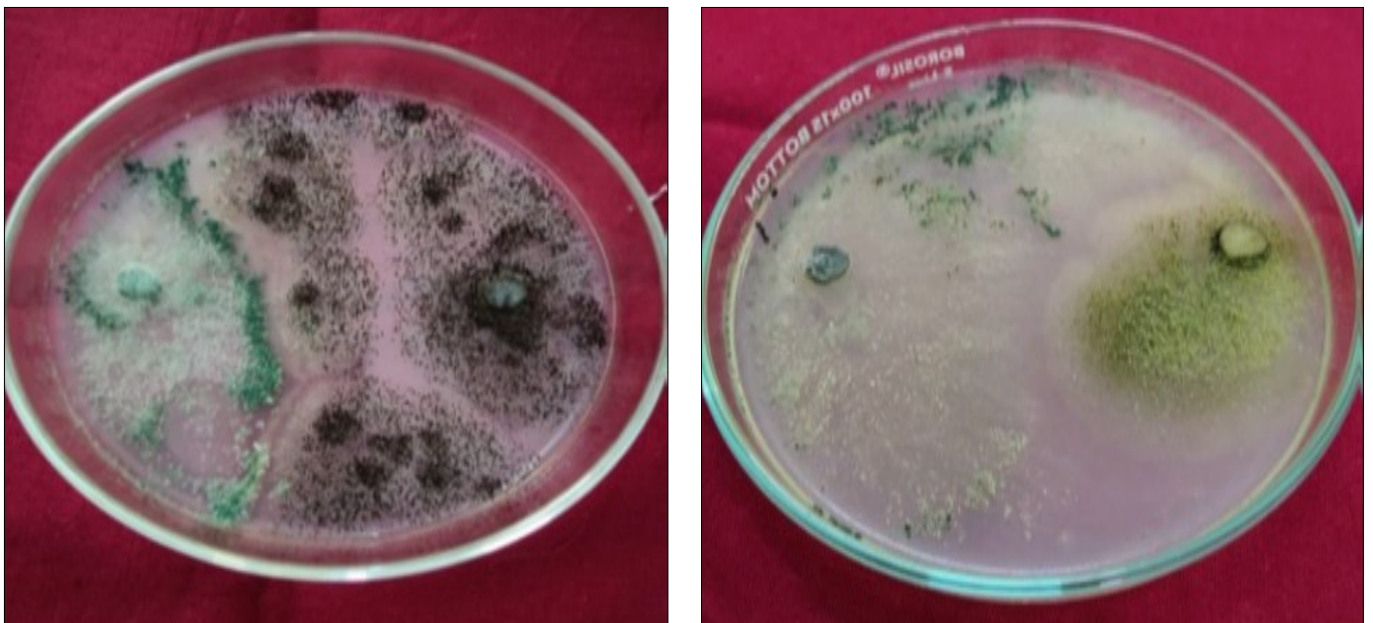
Fig. 2(b). *In vitro* evaluation of botanicals at 20 % concentration against *Aspergillus flavus*.

Table 3. *In vitro* evaluation of bioagents against *Aspergillus niger* and *Aspergillus flavus*.

Tr. no.	Treatments	<i>Aspergillus niger</i>		<i>Aspergillus flavus</i>	
		Colony diameter (mm)*	Inhibition (%)	Colony diameter (mm)	Inhibition (%)
T1	<i>Trichoderma asperellum</i>	56.33	36.47 (37.15)**	42.7	52.01 (46.15)
T2	<i>Pseudomonas fluorescens</i>	46.3	47.97 (43.83)	41.16	53.74 (47.14)
T3	<i>Trichoderma harzianum</i>	31.56	64.52 (53.44)	43.73	50.85 (45.48)
T4	Control (untreated)	89.00	0.00 (0.00)	89.00	0.00 (0.00)

*Average of three replications.

**Figures in parentheses are arc sin transformation values.

**Fig. 3(a).** *In vitro* evaluation of *Pseudomonas fluorescens* against *A. niger* and *A. flavus*.**Fig. 3(b).** *In vitro* evaluation of *Trichoderma asperellum* against *A. niger* and *A. flavus*.

The root length of the seedlings ranged from 5.37 cm to 6.67 cm. The longest root length was observed in seedlings from seeds treated with the pure culture of *T. asperellum* (6.67 cm), followed by those treated with the grain formulation of *T. asperellum* (5.79 cm). Seeds treated with *P. fluorescens* had a root length of 5.62 cm, while treatments with chlorothalonil and carbendazim resulted in root lengths of 5.60 cm and 5.51 cm, respectively. All these treatments produced longer roots compared to the untreated control (5.37 cm). The results obtained are presented in Table 4.

Discussion

Symptom assessment revealed characteristic signs of crown rot in greenhouse-grown cucumbers, including foliar yellowing and progressive wilting in grafted plants, thereby confirming the identity of *A. niger* as the causal organism (13). The pathogen's ability to induce disease was verified through both seed and soil inoculation studies (14, 15). Previous studies have highlighted that seed, soil and seedling inoculations remain the most reliable approaches for evaluating fungal pathogenicity in root and wilt diseases (16, 17).

Table 4. Growth promotion studies enhanced by using bioagents and fungicides

Tr. no.	Treatments	Germination (%)	Shoot length (in cm)	Root length (in cm)
T1	Grain formulation of <i>Trichoderma asperellum</i>	91.10 (72.64)**	16.44	5.79
T2	<i>Trichoderma asperellum</i> pure culture	93.02 (74.68)	18.59	6.67
T3	<i>Pseudomonas fluorescens</i>	90.86 (72.40)	15.81	5.62
T4	Carbendazim	83.11 (65.73)	15.67	5.51
T5	Chlorothalonil	84.62 (66.91)	15.78	5.60
T6	Control	72.27 (58.22)	14.81	5.37
	SE(m)	0.29	0.28	0.14
	CD 5 %	0.86	0.83	0.43
	CV	0.58 %	2.95 %	4.28 %

** Figures in parentheses are arc sine transformed values.

Evaluation of fungicides against *A. niger* revealed complete suppression of mycelial growth by carbendazim, carbendazim + mancozeb (12 % + 63 %), mancozeb + carbendazim (50 % + 25 %), azoxystrobin (18.2 %), difenoconazole (11.4 %) and the combination of trifloxystrobin (25 %) with tebuconazole (50 %) at 500 and 100 ppm concentrations. Similarly, hexaconazole and propiconazole at 1000 and 1500 ppm were equally effective (18). These results affirm the superior efficacy of systemic fungicides in mitigating fungal growth *in vitro*, corroborating previous findings on sterol biosynthesis-inhibiting triazoles.

Biocontrol evaluation revealed that *T. viride* and *T. harzianum* significantly inhibited the radial growth of *A. niger* under laboratory conditions (19). The efficacy of *T. harzianum* as a commercial biocontrol formulation against soil-borne fungal pathogens has been well established (20-22). The present findings found comparatively lower inhibition (64.5 %) by *P. fluorescens* against *A. flavus*, highlighting the greater efficiency of *Trichoderma*-based bioagents (23-25).

Among botanical treatments, garlic bulb extracts completely inhibited the mycelial growth of *A. niger* and *A. flavus*, achieving 100 % inhibition *in vitro* (26). Similarly, essential oils of eucalyptus and lemon showed marked antifungal activity against *A. niger*, *A. flavus*, *Penicillium chrysogenum* and *P. verrucosum*, even under vapor exposure (27). In agreement, extracts derived from garlic cloves, onion bulbs and neem leaves significantly suppressed mycelial growth of *A. niger* (28, 29). The convergence of these results confirms that bioactive plant metabolites can serve as sustainable and eco-friendly alternatives for managing seed- and soil-borne fungal pathogens in cucurbit ecosystems.

Conclusion

In most agricultural crop development programs, considerable focus is given to improving seed quality, which includes enhancing yield potential, maintaining purity and viability and ensuring strong germination. However, the presence of microorganisms can significantly affect many of these characteristics. The presence of fungi in cucumber seeds was examined using the ISTA standard method for seed health analysis. The results showed that cucumber seeds harbored *A. niger* and *A. flavus*. The pathogenicity of *A. niger* and *A. flavus* was confirmed by seed and soil inoculation methods in cucumber plants.

The highest mycelial growth inhibition was recorded in the fungicide carbendazim 12 % + mancozeb 63 % (100 %) and chlorothalonil (100 %) of *A. niger*. Similarly, the highest mycelial growth inhibition against *A. flavus* was observed with the

fungicides chlorothalonil (100 %) and propiconazole (100%). Among the botanicals tested at 20 % concentration, garlic exhibited the highest average mycelial growth inhibition (100 %) against both *A. niger* and *A. flavus*. Among the bioagents tested, *T. harzianum* recorded the highest percentage of mycelial inhibition (64.52 %) against *A. niger*, while *P. fluorescens* showed the highest inhibition (53.74 %) against *A. flavus*. In growth promotion studies, the pure culture of *T. asperellum* applied to cucumber seeds recorded the highest germination percentage (93.02 %), along with the greatest shoot length (18.59 cm) and root length (6.67 cm). Future studies should focus on integrating effective bioagents such as *T. asperellum* and botanical extracts like garlic with reduced chemical fungicide use to develop sustainable, eco-friendly seed treatment strategies for managing seed-borne pathogens in cucumbers.

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Authors' contributions

URS was involved in the collection of samples and *in vitro* evaluation of fungicides, botanicals and bioagents. GB was involved in reviewing the literature. SM conducted growth promotion studies. BRS analyzed the data and helped in editing the manuscript. PS analyzed the whole manuscript and communicated for approval of the final manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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