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Evaluation of culture filtrate of *Trichoderma* isolates with potential to induce Fusarium wilt resistance and promote early flower and fruit development in tomato

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Abstract

The current study was carried out at Department of Plant Pathology, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur in 2021-22 to 2022-23, to investigate the efficacy of culture filtrates from various *Trichoderma* isolates in controlling *Fusarium oxysporum* f. sp. *lycopersici* and enhancing tomato plant growth. Laboratory experiments demonstrated significant inhibition of radial mycelial growth by *Trichoderma* culture filtrates at both 5% and 10% concentrations. Among the culture of isolates, *Trichoderma* Nag (T₉) exhibited the highest inhibition (53.97%) and the most effective reduction in seed mortality, achieving the highest germination rates (94.61% in 2021-22, 92.67% in 2022-23). Culture filtrate of *Trichoderma* Ban (T₆) and *Trichoderma* Jab (T₇) also performed well, showing lower mortality and improved germination. Additionally, T₉ significantly promoted earlier flowering and fruiting compared to the control. The findings suggest that *Trichoderma* spp. not only control soil-borne pathogens like *F. oxysporum* but also enhance plant growth by improving nutrient uptake and inducing systemic resistance. This study supports the potential use of *Trichoderma* isolates as effective biocontrol agents and growth promoters in sustainable agriculture.

Keywords: Induce resistance, culture filtrate, Fusarium, tomato

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated and economically important crops globally, yet it remains vulnerable to various biotic stresses, including Fusarium wilt, a soil-borne disease caused by *Fusarium oxysporum* f. sp. *lycopersici*. Fusarium wilt severely affects plant health by obstructing water and nutrient flow, leading to significant yield losses. Managing this disease is challenging due to the pathogen's persistence in soil and its ability to rapidly adapt to chemical controls (Mudawi and Idris, 2015) [12]. Consequently, there is a growing interest in biological alternatives, particularly in the use of *Trichoderma* spp., which have emerged as a promising solution in sustainable agriculture. Climate change further exacerbates the vulnerability of crops like tomato, threatening global food security. In India, where agriculture is largely practiced by small and marginal farmers with limited resources, the impacts of climate change are particularly pronounced. The tropical climate, combined with these socioeconomic constraints, increases the risks to crop productivity and disease outbreaks (Bhardwaj *et al.*, 2022) [2]. The use of biological control agents, such as *Trichoderma* spp., offers an eco-friendly and cost-effective solution, especially in regions like India where chemical inputs are not always accessible. *Trichoderma* spp. are well-known for their ability to suppress plant pathogens through multiple mechanisms, including mycoparasitism, competition, and the production of antimicrobial compounds (Tyśkiewicz *et al.*, 2022) [18]. However, recent research has highlighted their additional role in inducing resistance in plants, which enhances the plant's defense response against pathogens like *Fusarium*. Culture filtrates of *Trichoderma* spp., containing bioactive secondary metabolites, have shown promise in triggering the plant's innate immune system, leading to enhanced resistance against Fusarium wilt (Shoresh *et al.*, 2018) [4]. Beyond pathogen control, certain *Trichoderma* isolates have been found to positively influence plant growth by promoting early flowering and fruiting. This dual functionality, in which *Trichoderma* not only induces resistance but also stimulates early

plant development, is particularly desirable for improving tomato yield (Mastouri *et al.*, 2017) ^[11]. Studies have shown that the application of *Trichoderma* culture filtrates can result in enhanced photosynthesis, water-use efficiency, and nutrient uptake, all of which contribute to early flowering and fruit set (Vinale *et al.*, 2019) ^[9]. In addition to improving crop yield, *Trichoderma* spp. have shown promise in enhancing the overall resilience of crops to environmental stresses such as drought and heat, which are becoming more prevalent due to climate change. Recent studies suggest that certain *Trichoderma* strains can improve water-use efficiency in crops, making them more tolerant to water deficits (Mastouri *et al.*, 2017) ^[11]. Moreover, the application of *Trichoderma* culture filtrates can enhance the bioavailability of essential nutrients like nitrogen and phosphorus, further supporting plant growth and development (Woo *et al.*, 2021) ^[21]. Inducing resistance through culture filtrates of *Trichoderma* spp. offers a sustainable and eco-friendly alternative to chemical fungicides, providing dual benefits of disease management and growth promotion. This approach aligns with the principles of sustainable agriculture, helping to reduce the reliance on synthetic chemicals while improving crop health and productivity. This study aims to explore new *Trichoderma* isolates with the ability to both induce resistance against *Fusarium* wilt and enhance early flowering and fruit development, ultimately contributing to the resilience and productivity of tomato cultivation.

Materials and Methods

The current experiment was conducted at Department of Plant Pathology and Student Instructional Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur during 2021-22 and 2022-23. The following work was conducted during the experiment described as below:-

Isolation, purification and identification of *Trichoderma* isolates

Collection of soil sample

Soil samples for the isolation of *Trichoderma* were collected from 12 different places of India, such as Ayodhya (Kumarganj, 26.5676° N latitude and 82.3205° E longitude), Jhansi (Punch, 25.4902° N latitude and 78.5685° E longitude), Hardoi (Kaurha, 27.4458° N latitude and 80.1312° E longitude), Lakhimpur (Barbata, 27.9528° N latitude and 80.7824° E longitude), Varanasi (Banaras Hindu Vishwa Vidyalaya Campus, 25.265184° N latitude and 82.994399° E longitude), Banda (Beldan, 25.5260° N latitude and 80.7864° E longitude) district of Uttar Pradesh, Jabalpur (Jawaharlal Nehru Krishi Vishwa Vidyalaya, 23.1450° N latitude and 79.9373° E longitude) district of Madhya Pradesh, Udham Singh Nagar (Govind Vallabh Pant University Campus, 29.0339° N latitude and 79.4776° E longitude) district of Uttarakhand, Nagaur (Khanpur Majhra,, 27.1564° N latitude and 74.1944° E longitude) district of Rajasthan, Anand (Anand Agriculture University campus, 22.5755° N latitude and 72.9322° E longitude) district of Gujarat, Ludhiana (Ayalikhurd, 30.8430° N latitude and 75.8498° E longitude) district of Punjab and Motihari (Chattavni, 26.6465° N latitude and 84.9135° E longitude) district of Bihar. *Trichoderma* Selective Medium used to isolate *Trichoderma* from different collected samples by using serial dilution technique and further purified on Potato Dextrose Agar medium (Elad *et*

al., 1981; Harman *et al.*, 2004) ^[5, 8]. The isolated *Trichoderma* spp. were identified under compound microscope on the basis of culture texture, colour, growth pattern of colony, conidiophores, phialides and conidia as per described by Harman (2000) ^[6].

Preparation of culture filtrate of *Trichoderma* spp.

Potato dextrose broth (PDB) was poured into sterile conical flasks, filling them about 1/4 of their capacity. Sterilized the flasks containing the broth by autoclaving at 121.6 °C (15 psi) for 15 minutes. With the help of a cork borer, small bits were cut from the pure culture of *Trichoderma* in the Petri plate and then they were transferred to the potato Dextrose Broth (PDB) poured conical flask using an inoculation needle under Laminar air flow. Covered the conical flasks with cotton plug to allow air exchange while preventing contamination. Placed the inoculated flasks on a shaker set at 25±1 °C for 21 days but at every 5-6 days, flasks have to be manually shaken. After the incubation period, the flasks were removed from the shaker. The broth was filtered to separate the fungal biomass from the liquid culture filtrate using sterile Whatman filter paper no. 1. Alternatively, the broth was centrifuged at 2500- 3000 RPM for 10-15 minutes to pellet the fungal biomass and then the supernatant was decanted. The supernatant was passed again through sterile Whatman filter paper no. 1 to remove any remaining spores or mycelial fragments to ensure that the culture filtrate was free of *Trichoderma* cells. The filtered culture filtrate was collected in sterile conical flask and labelled with the first three letter of name of location from where soil samples were collected for isolation of *Trichoderma* and date of preparation. The culture filtrate was stored at 4 °C until ready for use. All the collected *Trichoderma* isolates were used to prepare individual culture filtrates. These filtrates were applied as inducer in various treatments on tomato plants.

Isolation of *Fusarium*

The isolation of pathogen was performed in laboratory of Department of plant Pathology from infected plant sample collected from Student Instructional Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur. The identification of pathogen was performed under compound microscope as per description provided by Snyder and Hansen (1940) ^[17].

Seeds of tomato variety *Azad T-6* obtained from Department of Vegetable Science, C.S. Azad University of Agriculture and Technology, Kanpur used in this experiment and grown under wire house condition for raising nursery. Germination percentage, mortality rate, number of days taken for flowering, number of days taken for fruiting were tested by treating seeds with 10% concentration of culture filtrate of different isolates of *Trichoderma* spp. The pots seeded with tomato seed further inoculated with *F. o. f. sp. lycopersici*.

Bio-efficacy test

Bio-efficacy test of culture filtrate of different *Trichoderma* isolates has been performed at Laboratory of Department of Plant Pathology and by using Poison Food technique. The concentration of culture filtrate of *Trichoderma* @ 5 and 10% were tested, and radial growth of *Fusarium* measured in mm. The growth reduction through culture filtrate was calculated by given formulae:-

$$\text{Inhibition (\%)} = \frac{C - T}{C} \times 100$$

Where,

C- Radial growth of *Fusarium* in control plate

T- Radial growth of *Fusarium* in culture filtrate treated plate

Germination percent

Fourteen days after sowing (DAS), the number of treated seeds with culture filtrate @10%, that germinated in each treatment was counted and recorded. Germination percentage was calculated by given formula:-

$$\text{Germination \%} = \frac{\text{Number of germinated seed}}{\text{Total number of sown seed}} \times 100$$

Treatment details

Treatment 1 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Ayo) @ 10%, Treatment 2 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Jha) @ 10%, Treatment 3 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Har) @ 10%, Treatment 4 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Lak) @ 10%, Treatment 5 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Var) @ 10%, Treatment 6 = Seedling treatment + One foliar spray of culture filtrate @ 10% of *Trichoderma* (Ban), Treatment 7 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Jab) @ 10%, Treatment 8 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Usn) @ 10%, Treatment 9 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Nag) @ 10%, Treatment 10 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Ana) @ 10%, Treatment 11 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Lud) @ 10%, Treatment 12 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Mot) @ 10%, Treatment T₁₃ = Control (Untreated).

Statistical analysis

The data were analyzed by following the procedure of Randomized Block Design (RBD) and Completely Block Design (CRD). Data recorded in percentage were first transformed at Arc sin value (Fisher and Yates, 1963) $\sqrt{\sin^{-1}}$ before statistical analysis. Treatments were compared by means of critical difference (CD) at 5 percent level of significant.

Result and Discussion

Effect of culture filtrate of *Trichoderma* isolates on radial mycelial growth of *Fusarium oxysporum* f.sp. *lycopersici*

The effect of culture filtrate of different isolates of *Trichoderma* spp. tested in laboratory with 5 and 10% concentration and data pertaining from Table-1, showed that all the culture filtrates @ 5% concentration of different isolates of *Trichoderma* spp. inhibited radial mycelial growth of *F. o. f. sp. lycopersici* significantly. Growth was measured in mm for each treatment on 2, 4, 6 and 8 days after inoculation of pathogen. The maximum inhibition of radial growth of mycelial about 45.87% over control was recorded in T₉ treatment (Culture filtrate of *Trichoderma* Nag) representing 10.60, 22.97, 34.59 and 45.14 mm growth on 2, 4, 6 and 8 days after inoculation followed by treatment

T₆ (Culture filtrate of *Trichoderma* Ban) and treatment T₇ (Culture filtrate of *Trichoderma* Jab) representing 12.60, 27.83, 38.82 and 48.74 inhibited 41.55, and 12.92, 28.26, 40.60 and 49.05 mm inhibited 41.18% mycelium growth over control, respectively. It was observed that when a 10% concentration of culture filtrate of different isolates of *Trichoderma* spp. used, it inhibited mycelium growth of *F. o. f. sp. lycopersici* more effectively compared to 5% concentration. The culture filtrate @ 10% concentration of T₃ treatment (Culture filtrate of *Trichoderma* Har) showed the lowest percentage decreased among all the treatments (29.67%), but still effectively reduces growth compare to the control, recorded 12.31, 30.90, 40.43 and 59.84 mm radial mycelial growth. While, the treatment T₉ (Culture filtrate of *Trichoderma* Nag) exhibited the lowest growth (4.50, 15.97, 28.74 and 39.16 mm), showed highest percentage decreased (53.97%), indicating the most effective inhibition of radial mycelium growth. The treatment T₆ (Culture filtrate of *Trichoderma* Ban) and T₇ (Culture filtrate of *Trichoderma* Jab) inhibited 51.78 and 47.47% radial mycelial growth, respectively. These results suggest that these isolates are also promising candidates for biocontrol applications. The statistical parity between these two treatments further indicates that the antifungal efficacy of these isolates is comparable, likely due to similar profiles of antifungal metabolites. Previous research supports this observation, highlighting the consistency in biocontrol performance among different culture filtrate of *Trichoderma* isolates (Lo *et al.*, 2018; Keswani *et al.*, 2015; Mukherjee *et al.*, 2020). A recent study reported significant inhibition of mycelial growth in *Pythium undulatum* and *Phytophthora inundata* through the use of culture filtrates from *T. simmonsii* and *T. asperellum* (Ben M'henni *et al.*, 2022) ^[1].

Effect of culture filtrate of *Trichoderma* isolates on Germination percent and Mortality rate

The highest germination rate (94.61%) was observed in treatment T₉ (Culture filtrate of *Trichoderma* Nag), with the lowest among treated groups in T₃ (Culture filtrate of *Trichoderma* Har) and T₁₂ (Culture filtrate of *Trichoderma* Mot) recorded 80.33%. T₆ (Culture filtrate of *Trichoderma* Ban) and T₇ (Culture filtrate of *Trichoderma* Jab) followed with 92.67 and 89%, respectively. While, control (T₁₃) showed the lowest germination with 63% in 2021-22. As per Table-2, in 2022-23, T₉ again showed the highest germination (92.67%), followed by T₆ (89.33%), T₇ (87%) and T₁₀ (Culture filtrate of *Trichoderma* Ana) recorded 84.67%. All treated groups outperformed the control. Previous studies have shown that *Trichoderma* spp. can enhance plant growth by improving nutrient uptake, increasing resistance to stress and inducing systemic resistance against pathogens (Harman *et al.*, 2021; Contreras-Cornejo *et al.*, 2016) ^[7, 4]. Moreover, the reduction in seed mortality observed in treatments T₉ (Culture filtrates of *Trichoderma* Nag) T₆ (Culture filtrates of *Trichoderma* Ban) and T₇ (Culture filtrates of *Trichoderma* Jab) indicates the efficacy of culture filtrate in controlling wilt incidence, which is often attributed to soil-borne fungal pathogens such as *F. o. f. sp. lycopersici*. This result is consistent with the findings of Chagas *et al.* (2020) ^[3], reported that *Trichoderma* spp. effectively reduce disease incidence by outcompeting pathogenic fungi, producing antifungal metabolites and enhancing the plant's own defense mechanisms (65%).

In both 2021-22 and 2022-23, treatments with culture filtrates of *Trichoderma* spp. significantly reduced seed

mortality compared to the control (T₁₃). In 2021-22, the lowest mortality (6%) was observed in T₉ (Culture filtrate of *Trichoderma* Nag), while the control had the highest (37%). Among treated groups, T₁₂ (Culture filtrate of *Trichoderma* Mot) and T₃ (Culture filtrate of *Trichoderma* Har) showed the highest mortality (19.67%). Treatment T₆ (Culture filtrate of *Trichoderma* Ban) showed low mortality (7%) after T₉. In 2022-23, T₉ again showed the lowest mortality (7.33%), with T₆, T₇ (Culture filtrate of *Trichoderma* Jab), and T₁₀ (Culture filtrate of *Trichoderma* Ana) following. The control exhibited 35% mortality. Overall, *Trichoderma* filtrates reduced seed mortality and enhanced germination in tomato plants. This result is consistent with the findings of Chagas *et al.* (2020) [3], reported that *Trichoderma* spp. effectively reduce disease incidence by outcompeting pathogenic fungi, producing antifungal metabolites and enhancing the plant's own defense mechanisms. The variability in the performance of culture filtrate of different isolates of *Trichoderma* spp., as seen in the lower germination rates and higher mortality rates in treatments T₃ (Culture filtrate of *Trichoderma* Har) and T₁₂ (Culture filtrate of *Trichoderma* Mot), highlights the importance of selecting the right isolate for specific applications. This variability is well-documented in literature, where the effectiveness of *Trichoderma* isolates can vary depending on factors such as the strain, environmental conditions, and the crop being treated (Mastouri *et al.*, 2017; Singh *et al.*, 2021) [11, 16].

Effect of culture filtrate of *Trichoderma* isolates on number of days taken for flowering and fruiting

In current study the earliest flowering was observed in treatment T₉ (Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* Nag), where flowering occurred at 31.29 days after transplanting (Table-3). This is

significantly earlier than the control (T₁₃), where flowering took 55.78 days (in 2021-22 season). The efficacy of culture filtrate of *Trichoderma* Nag (T₉) in promoting early flowering could be attributed to its ability to enhance nutrient uptake and hormonal balance, which may promote the transition from vegetative to reproductive stages. Similar trends were observed in the 2022-23 cropping period, where treatment T₉ again showed the earliest flowering at 33.59 days, followed by culture filtrate of *Trichoderma* Ban (T₆) at 36.06 days and culture filtrate of *Trichoderma* Jha (T₂) at 38.73 days. In terms of number of days taken for first fruiting among all the treatments T₉ treatment (Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* Nag) showed the earliest fruit appearance at 38.96 days, while the control (T₁₃) has taken 63.78 days in 2021-22 (Table-3). This suggests that culture filtrate of *Trichoderma* spp. not only accelerates flowering but also promotes early fruit set, likely due to improved plant vigor and increased resistance to stress conditions (Woo *et al.*, 2006) [22]. In the 2022-23 season, T₉ once again led to the earliest fruit appearance at 41.26 days, followed by T₆ (Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* Ban) at 43.06 days, and T₇ (Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* Jab) at 49.39 days. The control treatment took 66.08 days, confirming the superiority of these culture filtrate treatments in reducing the time to fruiting. These findings supporting the role of *Trichoderma* spp. as plant growth promoters, which could be attributed their abilities to enhance nutrient availability, modulate plant hormone levels, and induce systemic resistance (Vinale *et al.*, 2008) [20]. Current findings also aligns with findings of Siddiquee *et al.* (2012) [15] they concluded that *Trichoderma* culture filtrates can be effectively used to accelerate the reproductive phase of plants, leading to earlier fruiting and flowering.

Table 1: Effect of culture filtrate of different isolates of *Trichoderma* spp. on radial mycelial growth of *Fusarium oxysporum* f. sp. *lycopersici* at different days after inoculation

Treatments	Radial mycelial growth at different days (mm) at 5%					Radial mycelial growth at different days (mm) at 10%				
	2 day	4 day	6 day	8 day	% decreased over control	2 day	4 day	6 day	8 day	% decreased over control
T ₁	21.50	31.61	53.49	67.10	19.53	12.93	24.53	50.00	55.56	34.70
T ₂	15.82	33.62	48.35	53.60	35.72	12.76	23.00	48.78	50.96	40.11
T ₃	18.82	33.25	52.50	63.31	24.08	12.31	30.90	40.43	59.84	29.67
T ₄	14.21	29.34	42.06	51.19	38.61	6.21	20.58	36.51	55.50	34.78
T ₅	16.60	32.36	49.60	62.46	25.10	10.05	25.10	42.76	56.92	33.11
T ₆	12.60	27.83	38.82	48.74	41.55	5.76	17.90	30.97	41.00	51.78
T ₇	12.92	28.26	40.60	49.00	41.18	5.97	18.13	33.36	44.70	47.47
T ₈	18.24	32.70	45.18	59.71	28.40	11.24	28.75	44.27	50.80	40.30
T ₉	10.60	22.97	34.59	45.14	45.87	4.50	15.97	28.74	39.16	53.97
T ₁₀	15.43	30.92	47.00	56.93	31.73	9.00	23.18	39.60	51.34	39.67
T ₁₁	15.16	30.00	51.68	62.80	24.69	9.48	33.20	46.76	57.72	32.16
T ₁₂	20.16	35.00	52.98	63.50	23.85	7.23	32.26	33.95	48.01	43.57
T ₁₃	27.16	45.86	64.71	83.39		21.00	43.79	63.19	85.00	
CD at 5%				0.938					1.652	
SEm±				0.323					0.568	
SEd				0.456					0.804	
CV				0.948					1.810	

Treatments

Treatment 1 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Ayo) @ 10%, Treatment 2 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Jha) @ 10%, Treatment 3 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Har) @ 10%, Treatment 4 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Lak) @ 10%, Treatment 5 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Var) @ 10%, Treatment 6 = Seedling treatment + One foliar spray of culture filtrate @ 10% of *Trichoderma* (Ban), Treatment 7 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Jab) @ 10%, Treatment 8 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Usn) @ 10%, Treatment 9 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Nag) @ 10%, Treatment 10 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Ana) @ 10%, Treatment 11 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Lud) @ 10%, Treatment 12 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Mot) @ 10%, Treatment T₁₃ = Control (Untreated).

Table 3: Effect of culture filtrate of different isolates of *Trichoderma* spp. @ 10% on germination and seed mortality of tomato

Treatments	2021-22		2022-23	
	Germination %	Seed mortality %	Germination %	Seed mortality %
T ₁	83.67	16.33	80.00	20.00
T ₂	82.67	17.33	83.33	16.67
T ₃	80.33	19.67	82.67	17.33
T ₄	86.33	13.67	83.33	16.67
T ₅	83.67	16.33	82.33	17.67
T ₆	92.67	7.33	89.33	10.67
T ₇	89.00	11.00	87.00	13.00
T ₈	81.67	18.33	80.67	19.33
T ₉	94.00	6.00	92.67	7.33
T ₁₀	82.33	17.67	84.67	15.33
T ₁₁	84.67	15.33	82.00	18.00
T ₁₂	80.33	19.67	81.33	18.67
T ₁₃	63.00	37.00	65.00	35.00
CD at 5%	2.188	1.447	2.212	1.560
SEm±	0.750	0.496	0.758	0.534
SEd	1.060	0.701	1.072	0.756
CV	1.557	5.183	1.588	5.332

Treatments

Treatment 1 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Ayo) @ 10%, Treatment 2 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Jha) @ 10%, Treatment 3 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Har) @ 10%, Treatment 4 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Lak) @ 10%, Treatment 5 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Var) @ 10%, Treatment 6 = Seedling treatment + One foliar spray of culture filtrate @ 10% of *Trichoderma* (Ban), Treatment 7 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Jab) @ 10%, Treatment 8 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Usn) @ 10%, Treatment 9 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Nag) @ 10%, Treatment 10 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Ana) @ 10%, Treatment 11 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Lud) @ 10%, Treatment 12 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Mot) @ 10%, Treatment T₁₃ = Control (Untreated)

Table 3: Effect of culture filtrate of different isolates of *Trichoderma* spp. @ 10% as inducer on flowering, fruiting and yield of tomato

Treatments	2021-22		2022-23	
	Appearance of first flowering (Days)	Appearance of first fruit (Days)	Appearance of first flowering (Days)	Appearance of first fruit (Days)
T ₁	40.10	52.43	42.40	54.73
T ₂	36.43	47.43	38.73	49.73
T ₃	44.77	55.76	47.07	58.06
T ₄	39.12	48.45	41.42	50.75
T ₅	43.76	54.76	46.06	57.06
T ₆	33.76	40.76	36.06	43.06
T ₇	35.09	47.09	37.39	49.39
T ₈	46.10	56.76	48.40	59.06
T ₉	31.29	38.96	33.59	41.26
T ₁₀	40.10	49.77	42.40	52.07
T ₁₁	43.43	54.10	45.73	56.40
T ₁₂	51.43	58.43	53.73	60.73
T ₁₃	55.78	63.78	58.08	66.08
CD at 5%	1.123	1.656	1.632	1.609
SEm±	0.385	0.567	0.559	0.551
SEd	0.544	0.802	0.791	0.780
CV	1.601	1.911	2.204	1.778

Treatments

Treatment 1 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Ayo) @ 10%, Treatment 2 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Jha) @ 10%, Treatment 3 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Har) @ 10%, Treatment 4 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Lak) @ 10%, Treatment 5 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Var) @ 10%, Treatment 6 = Seedling treatment + One foliar spray of culture filtrate @ 10% of *Trichoderma* (Ban), Treatment 7 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Jab) @ 10%, Treatment 8 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Usn) @ 10%, Treatment 9 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Nag) @ 10%, Treatment 10 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Ana) @ 10%, Treatment 11 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Lud) @ 10%, Treatment 12 = Seedling treatment + One foliar spray of culture filtrate of *Trichoderma* (Mot) @ 10%, Treatment T₁₃ = Control (Untreated)

Conclusion

The study highlights the effectiveness of culture filtrates from *Trichoderma* isolates in controlling *Fusarium*

oxysporum f. sp. *lycopersici* and enhancing tomato plant growth. Treatments with culture filtrate of *Trichoderma* Nag (T₉) consistently resulted in the highest germination rates,

lowest seed mortality, and greatest inhibition of fungal mycelial growth. Additionally, T₉ accelerated flowering and fruiting, outperforming other isolates and the control in both the 2021-22 and 2022-23 seasons. Culture filtrate of other isolates, such as *Trichoderma* Ban (T₆) and *Trichoderma* Jab (T₇), also showed promising results. The study underscores the biocontrol potential of *Trichoderma* spp., attributed to their production of antifungal metabolites, improvement of nutrient uptake and enhancement of plant defense mechanisms, making them valuable candidates for sustainable agriculture and pathogen management.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this study.

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