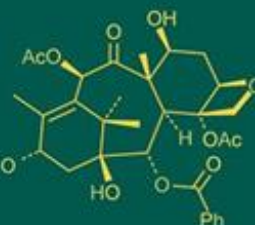
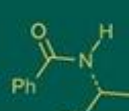
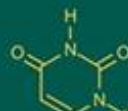
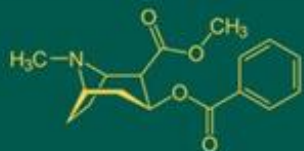


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In-vitro antifungal activity of bioagents, organic inputs and fungicides against *Fusarium oxysporum* f. sp. cubense inciting Panama wilt of banana

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Abstract

Panama wilt of banana, caused by *Fusarium oxysporum* f. sp. cubense (Foc), is one of the most destructive diseases limiting banana production worldwide. The present study was carried out during 2024-25 at the Department of Plant Pathology, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat, to evaluate the *in-vitro* efficacy of selected bioagents, organic inputs, and fungicides against Foc. Among bioagents, *Trichoderma harzianum* recorded the highest mycelial growth inhibition (70.27%), followed by *T. viride* (70.00%), while bacterial antagonists *Pseudomonas fluorescens* and *Bacillus subtilis* showed moderate suppression. Organic inputs at higher concentrations (15%) performed better, with Jeevamrutha (71.11%) and Beejamrutha (70.56%) being most effective, whereas Vermiwash (21.86–50.56%) was least effective. Fungicides proved highly suppressive, with carbendazim 50% WP, propiconazole 25% EC, tebuconazole + trifloxystrobin, and carbendazim + mancozeb showing complete (100%) inhibition at both concentrations. The findings suggest that while fungicides remain the most potent option, integration with bioagents and organic inputs could provide an eco-friendly and sustainable approach to the management of Panama wilt.

Keywords: Banana, fusarium oxysporum f. sp. cubense, bioagents, organic inputs, fungicides, panama wilt

Introduction

Banana (*Musa* spp.) is one of the most important tropical fruits grown globally and is a major source of food, nutrition and income. India leads global production, contributing about 27 per cent of total output, with Gujarat ranking first in productivity [1, 2]. Despite its economic importance, banana cultivation faces severe threats from several diseases, among which Panama wilt, caused by *Fusarium oxysporum* f. sp. cubense (Foc), is the most destructive [3, 4].

The pathogen infects through roots and colonizes vascular tissues, resulting in yellowing, wilting, pseudostem splitting and plant death, leading to yield losses up to 60-90 per cent [5, 6]. Historically, Foc Race 1 devastated 'Gros Michel' plantations, while the emergence of Tropical Race 4 (TR4), capable of infecting Cavendish cultivars, now poses a global biosecurity concern [7, 8]. In India, both Foc R1 and TR4 have been reported from major banana-growing states, including Gujarat [9, 10, 11].

Conventional control practices such as soil fumigation, crop rotation and fungicide application have offered limited success against this soilborne pathogen [12, 13, 14]. The use of resistant cultivars provides some relief, but the emergence of virulent strains restricts their long-term utility. Therefore, eco-friendly strategies such as biological control and organic amendments are gaining significance. Several studies have demonstrated the antagonistic activity of *Trichoderma* spp. and *Pseudomonas fluorescens*, as well as the effectiveness of organic inputs and compatible fungicides, in suppressing Panama wilt [15, 16, 17].

Considering the increasing incidence of Panama wilt in India and the limitations of conventional management, the present study was undertaken to evaluate the efficacy of selected bioagents, organic inputs and fungicides under *in-vitro* conditions against Foc.

Materials and Methods

The present investigation was conducted in the Department of Plant Pathology, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat, during the year 2024-25.

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In-vitro Bio-efficacy of Bioagents

The antagonistic potential of five bioagents (*Trichoderma harzianum*, *T. asperellum*, *T. viride*, *Bacillus subtilis* and *Pseudomonas fluorescens*) was evaluated *in-vitro* against *Foc* using the dual culture technique [18]. Cultures of *Trichoderma* spp. were obtained from the Department of Plant Pathology, BACA, AAU, Anand; *Pseudomonas fluorescens* from the Department of Agricultural Microbiology, BACA, AAU, Anand and *Bacillus subtilis* from the AICRP on Biological Control Research Laboratory, BACA, AAU, Anand. The radial growth of the pathogen was recorded at 24 h intervals, and the per cent growth inhibition (PGI) was calculated using the formula of Vincent (1947) [19],

$$\text{Per cent Growth Inhibition (PGI)} = \frac{DC - DT}{DT} \times 100$$

The experiment was conducted in a Completely Randomized Design (CRD) with six treatments and four replications.

In-vitro Bio-efficacy of Organic Inputs

Five organic inputs (Cow-urine, panchagavya, jeevamrutha, beejamrutha and vermiwash) were evaluated *in-vitro* against *Foc* using the poisoned food technique [20]. Each input was tested at two concentrations (10% and 15%), while PDA without amendments served as control. Fresh cow urine was collected from the Livestock Research Station, KU, Anand, and vermiwash from the Agronomy Farm, AAU, Anand. *Panchagavya* was prepared as per NCOF guidelines [21], while jeevamrutha and beejamrutha were prepared following Devvrat (2020) [22].

The experiment was laid out in a CRD with 11 treatments (five inputs × two concentrations + control) and three replications. Radial growth of the pathogen was recorded, and per cent growth inhibition was calculated as described by Vincent (1947) [19].

In-vitro Bio-efficacy of Fungicides

Nine fungicides were evaluated *in-vitro* against *Foc* using the

poisoned food technique [20]. Each fungicide was tested at two concentrations (250 ppm and 500 ppm), while PDA without fungicides served as control. The experiment was laid out in CRD with 19 treatments (nine fungicides × two concentrations + control) and three replications. Radial growth of the pathogen was recorded, and per cent growth inhibition was calculated as described by Vincent (1947) [19].

Statistical Analysis

Data for all experiments were analyzed statistically, and the critical difference (C.D.) at a 5% significance level was calculated to compare treatment means.

Results

In-vitro Bio-efficacy of Bioagents against Foc

All tested bioagents exhibited a significant inhibitory effect on the mycelial growth of *Foc*. *Trichoderma harzianum* showed the highest inhibition (70.27%), followed by *T. viride* (70.00%) and *T. asperellum* (51.94%). The bacterial antagonists *Pseudomonas fluorescens* and *Bacillus subtilis* showed 50.55 per cent and 46.91 per cent inhibition, respectively. The untreated control recorded full growth (90 mm) with no inhibition (Table 1; Fig 1).

Table 1: *In-vitro* evaluation of bioagents against *Foc*

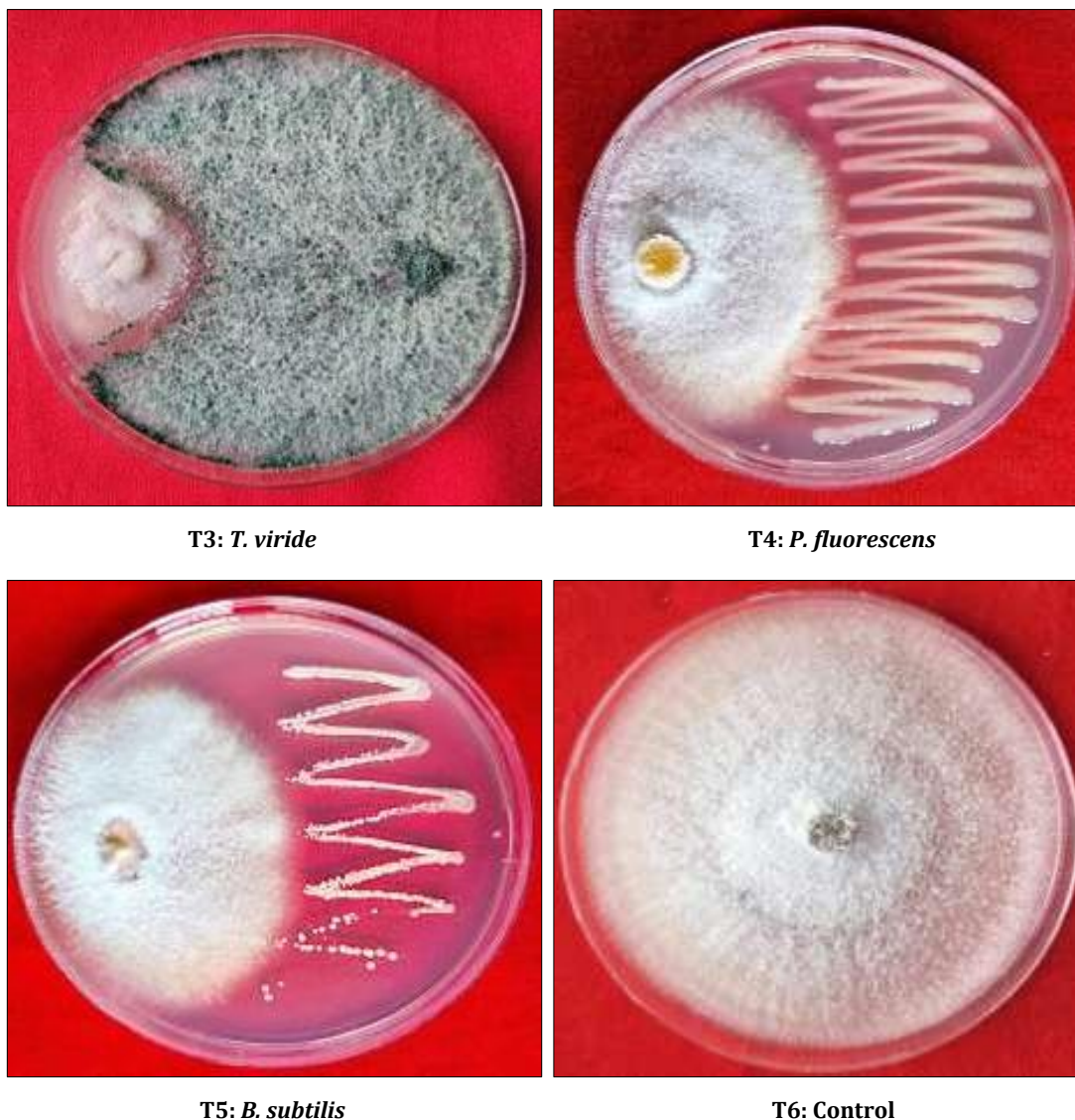
Tr. No.	Treatments	Mycelial radial growth (mm)	Growth inhibition (%)
T ₁	<i>Trichoderma harzianum</i>	26.75	70.27
T ₂	<i>Trichoderma asperellum</i>	43.25	51.94
T ₃	<i>Trichoderma viride</i>	27.00	70.00
T ₄	<i>Pseudomonas fluorescens</i>	44.50	50.55
T ₅	<i>Bacillus subtilis</i>	47.78	46.91
T ₆	Control	90.00	-
	S.E.m.±	0.77	-
	C.D. at 5%	2.27	-
	C.V. (%)	3.29	-



T1: *T. harzianum*



T2: *T. asperellum*

T3: *T. viride*T4: *P. fluorescens*T5: *B. subtilis*

T6: Control

Fig 1: Effect of bioagents against *Foc* under *in-vitro* conditions***In-vitro* Bio-efficacy of Organic Inputs against *Foc***

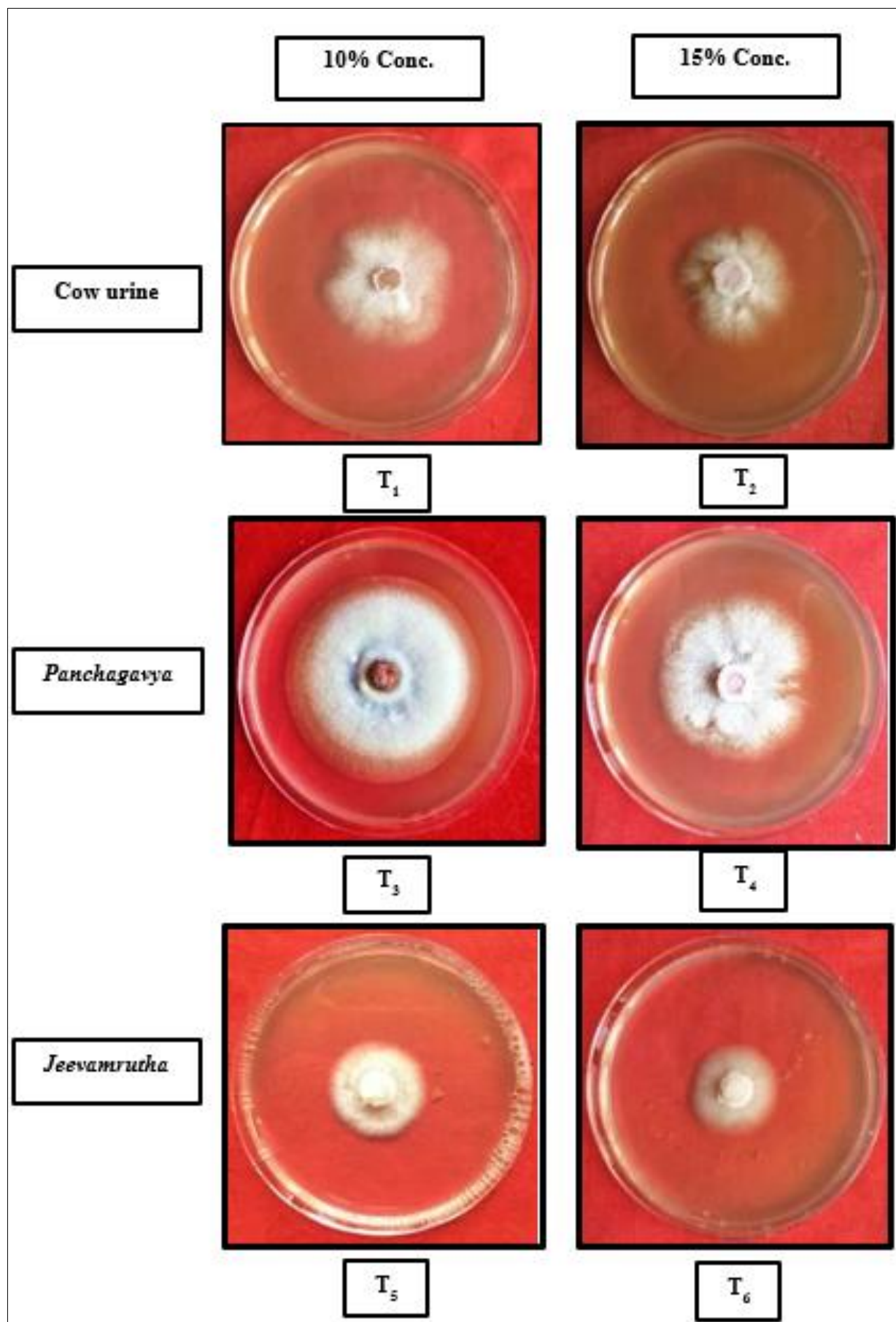
All organic inputs exhibited antifungal activity, with treatments at 15 per cent concentration proving more effective than their 10 per cent counterparts. Among them, *Jeevamrutha* (15%) recorded the highest inhibition (71.11%), followed by *Beejamrutha* (15%) (70.56%) and *Jeevamrutha* (10%) (65.33%). Cow urine (Fresh) showed 64.08 per cent and

57.44 per cent inhibition at 15 per cent and 10 per cent, respectively. *Beejamrutha* (10%) restricted the growth by 61.04 per cent. *Panchagavya* showed moderate inhibition with 50.70 per cent (15%) and 29.81% (10%). Vermiwash was least effective with 21.86 per cent (10%) and 50.56 per cent (15%) inhibition. The untreated control recorded full growth (90 mm) with no inhibition (Table 2; Fig 2).

Table 2: *In-vitro* evaluation of organic inputs against *Foc*

Tr. No.	Treatments	Concentration (%)	Mycelial radial growth(mm)	Growth inhibition (%)
T1	Cow urine (Fresh)	10	38.30 ^e	57.44
T2		15	32.33 ^{fg}	64.08
T3	<i>Panchagavya</i>	10	63.17 ^c	29.81
T4		15	44.37 ^d	50.70
T5	<i>Jeevamrutha</i>	10	31.20 ^g	65.33
T6		15	26.00 ^h	71.11
T7	<i>Beejamrutha</i>	10	35.06 ^f	61.04
T8		15	26.50 ^h	70.56
T9	Vermiwash	10	70.33 ^b	21.86
T10		15	44.50 ^d	50.56
T11	Control		90.00 ^a	-
		S.E.m.±	0.87	-
		C.D. at 5%	2.53	-
		C.V. (%)	3.28	-

Note: Treatment means with the letter/letters in common are not significant by Duncan's new multiple range test (DNMRT) at 5 % level of significance



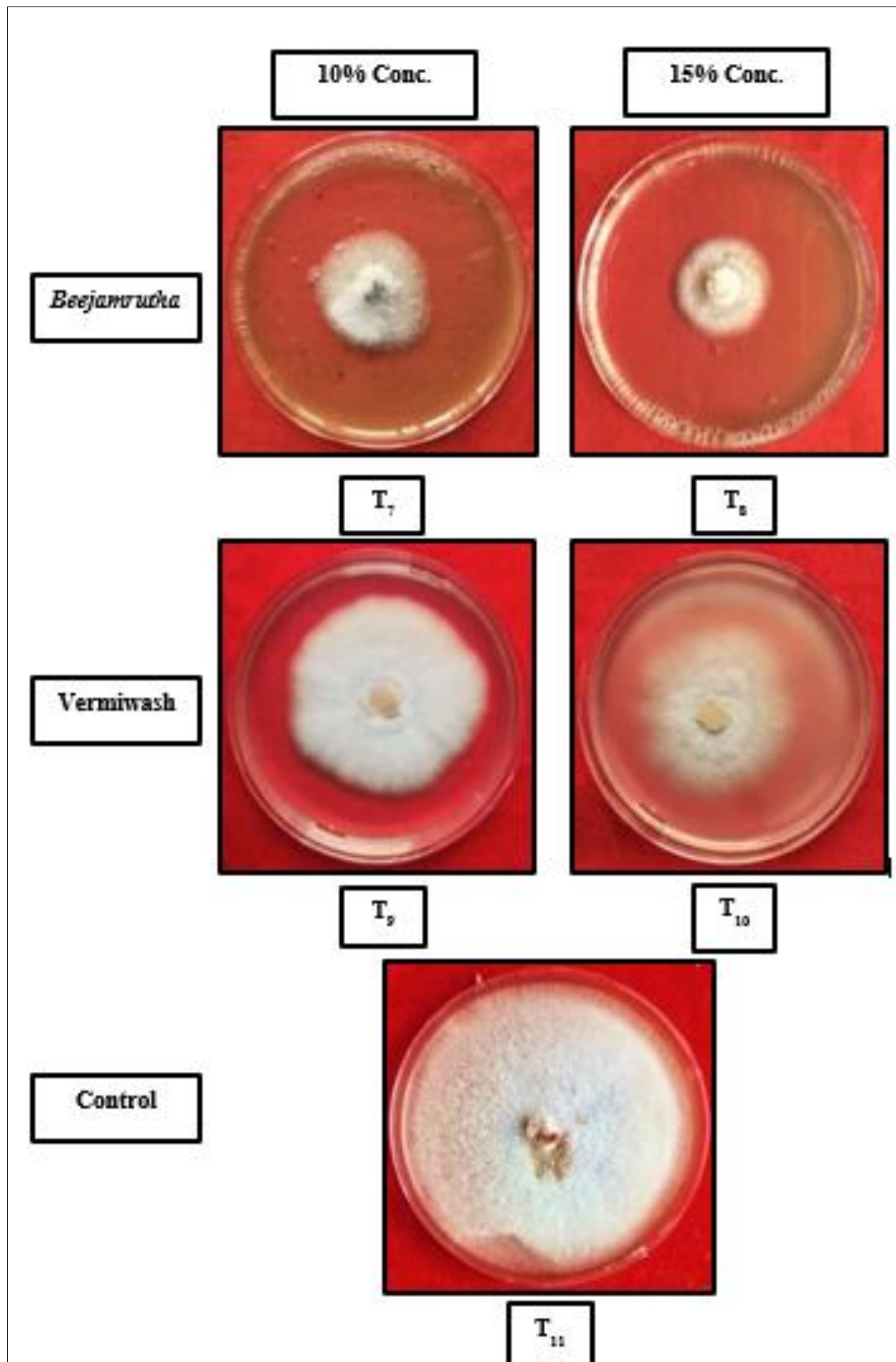


Fig 2: Effect of organic inputs against *Foc* under *in-vitro* conditions

In-vitro Bio-efficacy of Fungicides against Foc

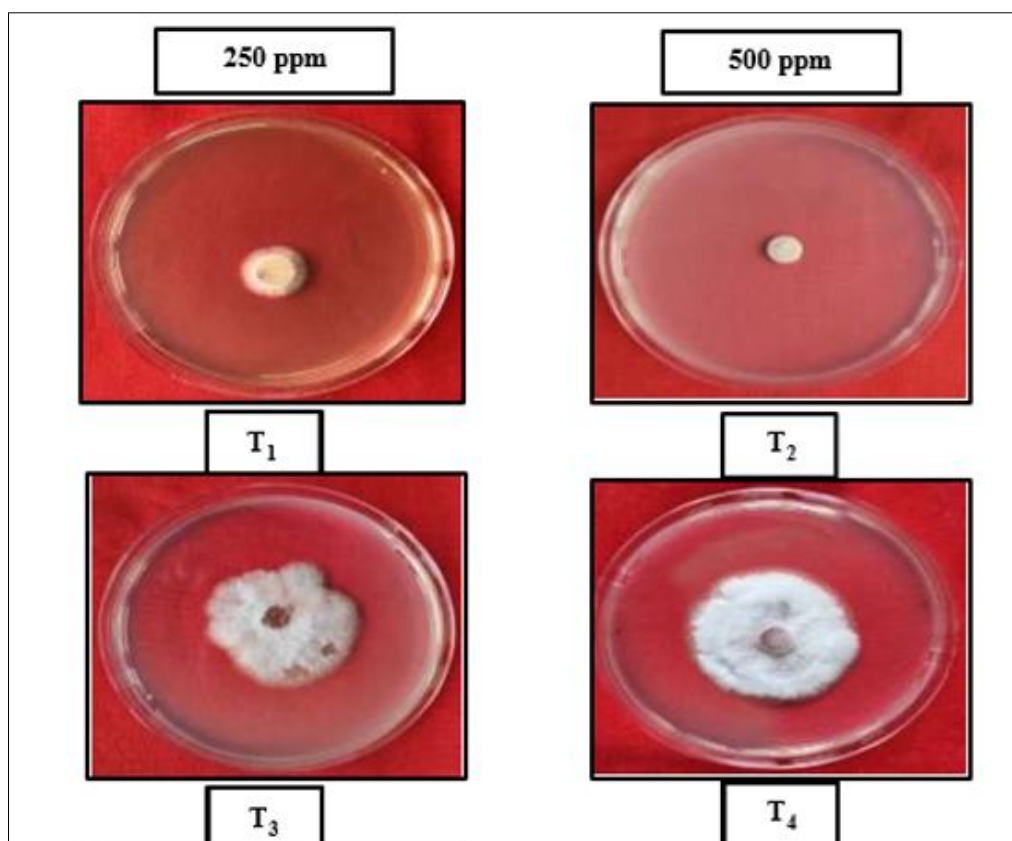
Among the tested fungicides, complete inhibition (100%) was observed in carbendazim 50% WP (500 ppm), propiconazole 25% EC (500 ppm), tebuconazole 50% + trifloxystrobin 25% WG (250 and 500 ppm), and carbendazim 12% + mancozeb 63% WP (250 and 500 ppm). Difenonazole 25% EC at 500 ppm (81.48%; 16.67 mm colony diameter) and fluopyram 17.7% + tebuconazole 17.7% SC at 500 ppm (75.37%; 22.17 mm) followed next in effectiveness.

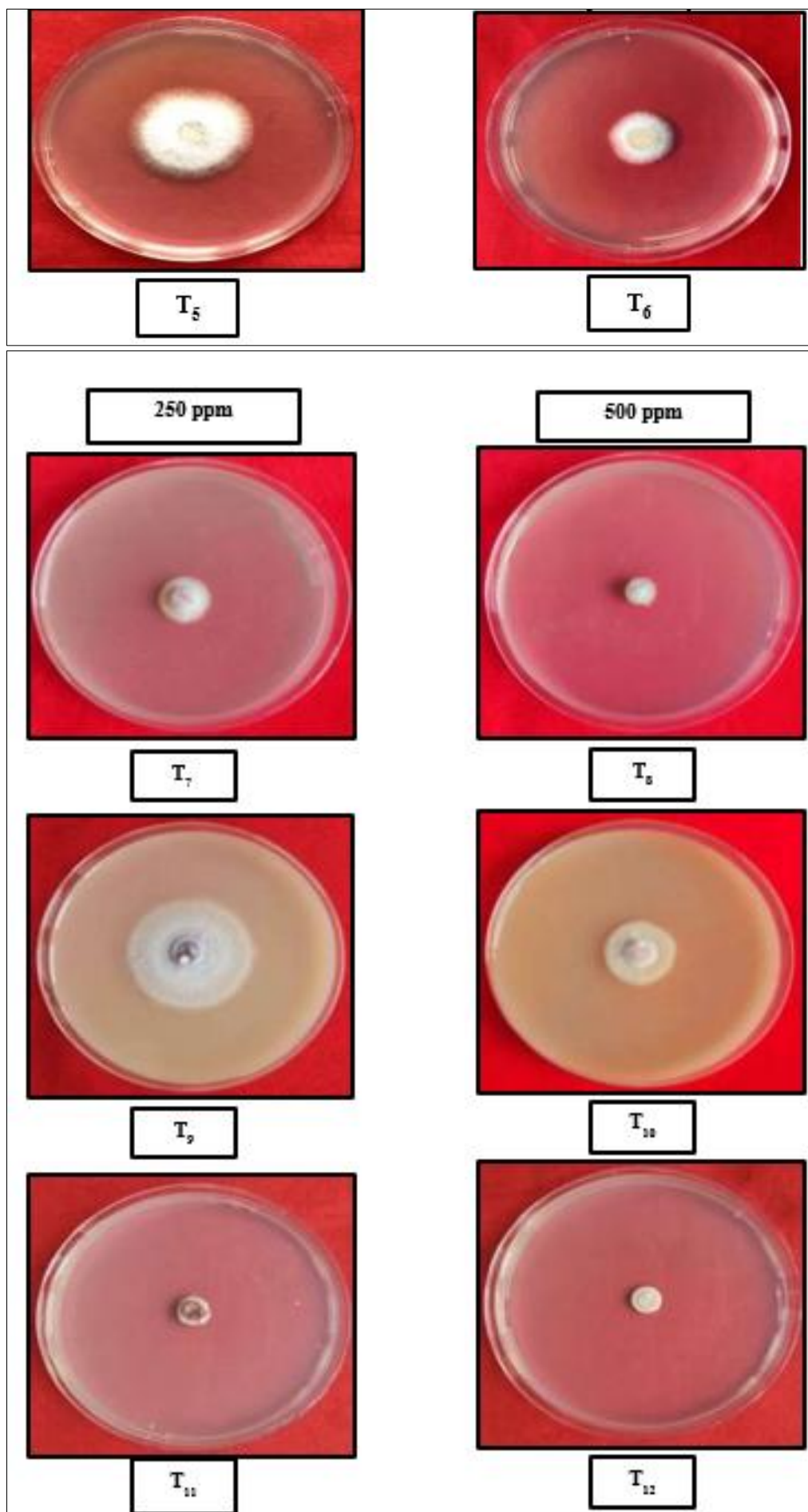
Other promising fungicides included azoxystrobin 18.2% + difenoconazole 11.4% SC (73.33%; 24.00 mm) and metiram 55% + pyraclostrobin 5% WG (73.00%; 24.30 mm), both at 500 ppm. At 250 ppm, carbendazim 50% WP and propiconazole 25% EC were highly effective, recording 88.44% and 88.40% inhibition, respectively, and were statistically at par. Difenonazole 25% EC (63.33%) and azoxystrobin 23% EC (45.89%) at 250 ppm showed moderate suppression, with the latter being least effective among the tested fungicides.

Table 3: In-vitro bio-efficacy of fungicides against Foc

Tr. No.	Treatments	Concentration (ppm)	Mycelial radial growth(mm)	Growth inhibition (%)
T ₁	Carbendazim 50% WP	250	10.40 ^j	88.44
T ₂		500	0.00 ^k	100.00
T ₃	Azoxystrobin 23% EC	250	48.70 ^b	45.89
T ₄		500	38.60 ^d	57.11
T ₅	Difenonazole 25% EC	250	33.00 ^f	63.33
T ₆		500	16.67 ⁱ	81.48
T ₇	Propiconazole 25% EC	250	10.53 ^j	88.30
T ₈		500	0.00 ^k	100.00
T ₉	Metiram 55% + pyraclostrobin 5% WG	250	37.50 ^d	58.33
T ₁₀		500	24.30 ^g	73.00
T ₁₁	Tebuconazole 50% + trifloxystrobin 25% WG	250	0.00 ^k	100.00
T ₁₂		500	0.00 ^k	100.00
T ₁₃	Azoxystrobin 18.2% + difenoconazole 11.4% SC	250	35.17 ^e	60.92
T ₁₄		500	24.00 ^g	73.33
T ₁₅	Carbendazim 12% + mancozeb 63% WP	250	0.00 ^k	100.00
T ₁₆		500	0.00 ^k	100.00
T ₁₇	Fluopyram 17.7%+ tebuconazole 17.7% SC	250	42.33 ^c	52.97
T ₁₈		500	22.17 ^h	75.37
T ₁₉	Control	-	90.00 ^a	-
	S.E.m.±		0.60	-
	C.D. at 5%		1.78	-
	C.V. (%)		4.67	-

Note: Treatment means with the letter/letters in common are not significant by Duncan's new multiple range test (DNMRT) at 5 % level of significance





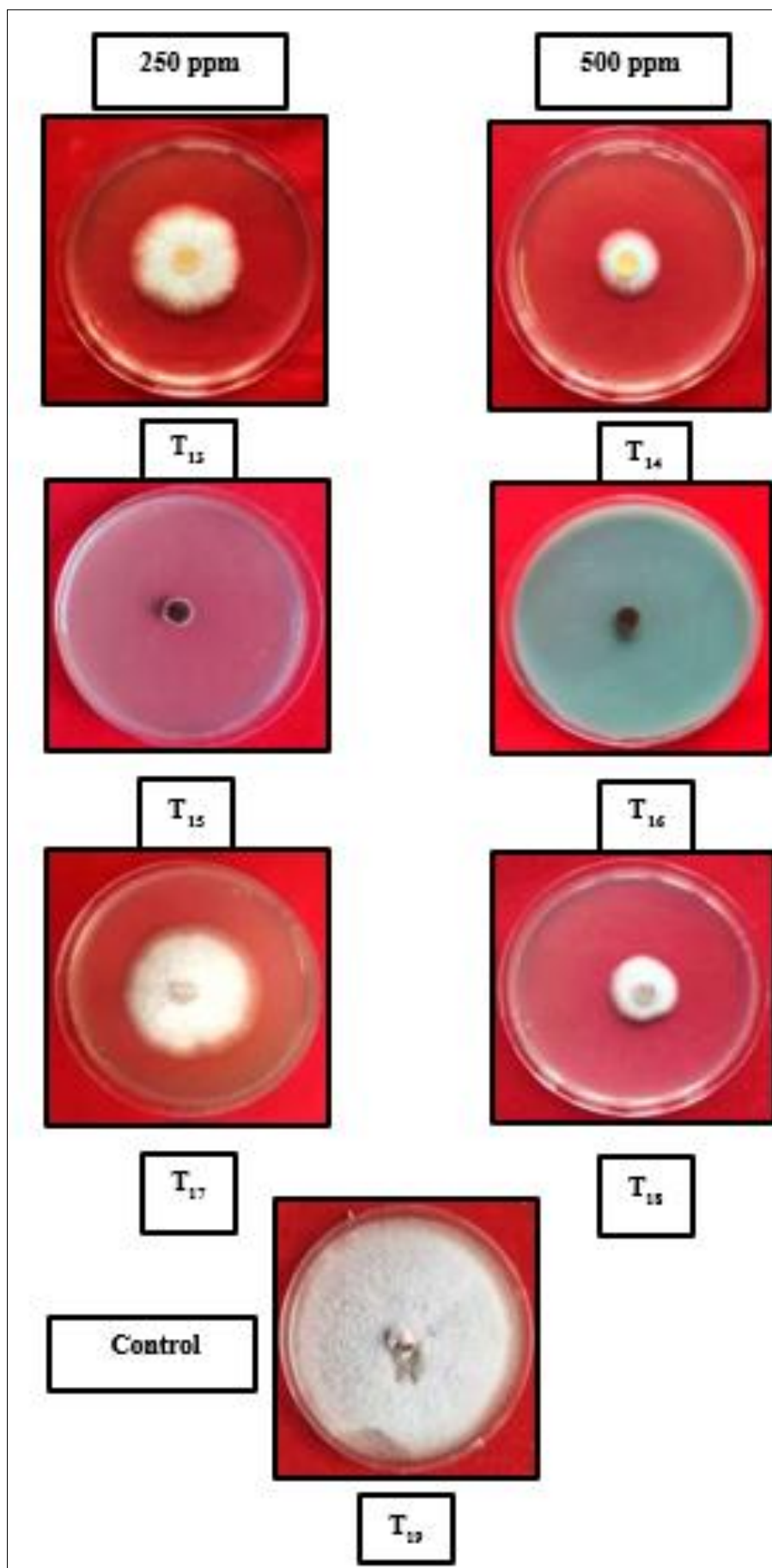


Fig 3: Effect of fungicides against *Foc* under *in-vitro* conditions

Discussion

The study highlights the effectiveness of different strategies for managing *Fusarium oxysporum* f. sp. cubense. Among bioagents, *Trichoderma harzianum* was most effective, which agrees with earlier reports [23, 24]. The moderate efficacy of *T. asperellum*, *P. fluorescens* and *B. subtilis* suggests their potential in combination for broader control.

Organic inputs like jeevamrutha and beejamrutha showed strong inhibition, supporting findings of [25, 26]. Cow urine and panchagavya showed moderate suppression, while Vermiwash was least effective, indicating that these inputs may serve as supplementary tools.

Among fungicides, carbendazim, propiconazole, tebuconazole + trifloxystrobin, and carbendazim + mancozeb recorded complete inhibition, consistent with previous studies [27, 28, 29]. Difenconazole and fluopyram + tebuconazole were highly effective, while protectants like azoxystrobin showed only moderate activity.

Overall, fungicides remain the most potent suppressants, but integration with bioagents and organic inputs offers a sustainable strategy for long-term management of Panama wilt.

Conclusion

The present investigation revealed significant variation in the antifungal activity of bioagents, organic inputs, and fungicides against *Fusarium oxysporum* f. sp. cubense. Among bioagents, *Trichoderma harzianum* emerged as the most effective antagonist, while jeevamrutha and beejamrutha performed best among organic inputs at higher concentrations. Fungicides such as carbendazim, propiconazole, tebuconazole + trifloxystrobin, and carbendazim + mancozeb provided complete inhibition of *Foc* under *in-vitro* conditions, confirming their superior efficacy. However, considering sustainability, integration of effective bioagents and organic inputs along with judicious use of fungicides can offer a reliable strategy for long-term management of Panama wilt in banana cultivation.

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