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Research Article

Evaluation of different biorational modules against *Fusarium* wilt of banana incited by *Fusarium oxysporum* f. sp. *cubense*

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ABSTRACT: Banana is the most commonly grown fruit worldwide. Banana production can be threatened by various fungal, bacterial, and viral diseases of which Panama wilt of banana caused by *Fusarium oxysporum* f. sp. *cubense* is a major problem in the Karur district, especially in Karpooravalli (ABB) and Ney Poovan (AB) cultivars. In this view, an experiment was conducted with different biocontrol agents and chemicals in the farmers' field at two different locations, Neidalur North and Neidalur South of Thogamalai block of Karur district, to evaluate the efficacy and suitability of biocontrol agents and other treatments in controlling Fusarium wilt disease in banana during the year 2024-25. The study results revealed that the incidence of Fusarium wilt was recorded less in TO-4 treatment, with 8.4% in Karpooravalli and 8.9% in Ney Poovan cultivars, compared to other treatments. Corm treatment with 0.25% Carbendazim solution one day before planting, followed by soil application of NRCB microbial consortia at the time of planting and at the second, fourth and sixth months after planting, effectively reduced the Fusarium wilt disease. The banana plants in TO-4 quality had a large number of high-quality leaves, the highest number of quality fruits, and a large bunch weight, in addition to suppressing the pathogen.

KEYWORDS: Banana, *Fusarium oxysporum* f. sp. *cubense, Fusarium* wilt, NRCB microbial consortia, *Trichoderma asperellum*

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INTRODUCTION

Bananas (*Musa* spp) belonging to the order Zingiberales and the family Musaceae, are one of the most widely traded fruit crops worldwide. They are extensively grown in tropical and subtropical areas and hold a significant position in the global market. Bananas hold a significant position as the fourth most important fruit crop in the world (Tinzaara *et al.*, 2024). Currently, bananas are cultivated in more than 150 countries worldwide, with the highest production (120 million tonnes) concentrated in Asia, Latin America, and Africa, whereas India and China are the largest producers in the domestic market (FAO, 2021). India is a significant player in the global banana market and holds a position as the second-largest producer of bananas worldwide, accounting for 20.1% of the global production (Pankaj *et al.*, 2025). Banana is rich in fibre, potassium, vitamin B6, vitamin C, antioxidants, and phytonutrients (Adhikary *et al.*, 2024).

The productivity of bananas is threatened by various diseases, such as Black Sigatoka (*Pseudocercospora fijiensis*), Panama disease (*F. oxysporum* f. sp. *cubense*), moko (*Ralstonia solanacearum* race 2), Yellow Sigatoka (*Mycosphaerella musicola*), Erwinia rot and mosaic (*Tobacco mosaic* virus) (Jiménez *et al.*, 2025). Among the diseases, Panama wilt disease is a devastating disease caused by *F. oxysporum* f. sp. *cubense* that affects banana plants and can cause yield loss up to 100%. Panama wilt disease can spread quickly and can cause serious economic losses for banana growers. The disease is particularly devastating in tropical and subtropical regions where bananas are grown for commercial purposes. The production of banana plants and the quality of fruit produced can be impacted by Panama wilt disease. The disease is also known to cause wilting and chlorosis on the leaves of affected plants (Sangeetha *et al.*, 2023). The symptoms of this disease include yellowing of the entire leaves, starting from the lower leaves towards the upper leaves. The leaves hang around the pseudostem. Later longitudinal splitting of the pseudostem and finally the death of the plant (Zhang *et al.*, 2022).

In India, most of the farmers used many fungicides like Carbendazim, Carbendazim+Mancozeb (Dithane M-45), Propiconazole, Tebuconazole 50% +Trifloxystrobin 25% 75WG (Nativo) and copper oxychloride (Blue copper) to manage this disease through foliar spraying, soil drenching and pseudo stem injection. Fungicide resistance and environmental pollution resulted from repeated and excessive

doses of fungicide application. Although some traditional strategies, such as using fungicides or soil amendments, crop rotation, field sanitation, flooding fields, and solarisation, have been employed, they have not been successful in managing the disease (Roberts *et al.*, 2024).

By using biocontrol, soil properties can be enhanced and beneficial microbes can be boosted for banana growth in the rhizosphere, which will lead to a significant reduction in the incidence of FWB (Zhu *et al.*, 2023). Trichoderma and Streptomyces have been previously reported as biocontrol agents against Fusarium wilt disease of banana (Wang *et al.*, 2022). Inhibiting pathogen growth and promoting plant health are achieved by beneficial rhizospheric microbes that are from the genera Trichoderma, Actinobacteria, and Bacillus, which are found in soil (Dlamini *et al.*, 2022). Bacillus produces antifungal compounds, while Trichoderma and Streptomyces are known to produce enzymes such as chitinase and glucanase that degrade the cell walls of pathogenic fungi (Sahodaran *et al.*, 2019).

Banana growers have embraced biological control because it saves farmers from the high cost of pesticides and prevents ecosystem damage. Talc-based bioinoculants were highly effective in controlling soil-borne pathogens and multiplied in the soil, preventing it from being destroyed by the next year. Eco-friendly bio-inoculants can be used to prevent the lingering effects of fungicides and lower the cost of input. Keeping in this view, ICAR Krishi Vigyan Kendra, Karur, Tamil Nadu took an initiative to evolve location location-specific eco-friendly technology module for the management of Fusarium wilt disease in Banana. For this, different treatments like NRCB Microbial consortia, TNAU strains of *Trichoderma viride* and *Bacillus subtilis* and chemicals were tested in the farmer's field at two different locations to verify the efficacy and suitability for controlling Fusarium wilt disease in Banana.

MATERIALS AND METHODS

The experiment was carried out in three farmers' fields at primarily Karpooravalli (ABB) and Ney Poovan (AB) banana varieties growing villages *viz.*, Neidalur North and Neidalur South of Thogamalai block of Karur district. The farming conditions for banana cultivation in these areas were characterised by low land conditions and clay loam. The majority of irrigation was carried out through canals connected to the Cauvery River. The experiment was laid out in a Randomised Block Design. The treatments were imposed on the banana as detailed below.

Treatment details

Treatment option 1 (TO-1): Banana Suckers dipping with 0.25% Carbendazim solution for 15 minutes one day before planting.

Treatment option 2 (TO-2): NRCB (Microbial consortia): Soil application of microbial consortia (*Trichoderma asperellum* + *Bacillus flexus*) @ 50g per pit at the time of planting, second, fourth and sixth months of planting.

Treatment option 3 (TO-3): TNAU: Soil application of *Trichoderma asperellum* and *Bacillus subtilis,* each 2.5 Kg/ha mixed with 100 kg well-decomposed Farm Yard Manure along with 100 Kg Neem cake.

Treatment option 4 (TO-4): Treatment 1 + Treatment 2

Treatment option 5 (TO-5): (Farmers Practice): Soil drenching with a 0.2% solution of Tebuconazole 50% +Trifloxystrobin 25% 75WG at the second and fourth months after planting.

Treatment option 6 (TO-6): Control plot As Check

Disease incidence assessment

The percentage disease incidence was calculated by the following formula given by Mayee and Datar in 1986.

Disease incidence (%) = (Number of infected plants / Total number of plants observed) X 100

To avoid the error, a uniform plot size of 12000 m^2 area (@ 2000m^2 per treatment) was chosen for the field trial with the above-mentioned modules and the check. All the plots were irrigated through Drip irrigation to avoid flooding. The flooding conditions are not suitable for *Trichoderma* multiplication. In each plot, the incidence of wilt was assessed by counting the total number of plants and infected plants and expressing it as per cent incidence.

RESULTS AND DISCUSSION

Survey on the incidence of Panama wilt disease caused by *F. oxysporum* f. sp. *cubense* in major banana-growing villages of Karur district

A survey was conducted in major banana-growing villages of Karur district during the year 2023-24 to assess the incidence of Fusarium wilt disease, with a range of 25.45% to 43.78% in Karpooravalli (ABB) and Ney Poovan (AB) cultivars. Among the villages, Neidalur North showed the highest disease incidence rate of 41.5% in Karpooravalli (ABB), followed by Neidalur South Village with 38.35% in Ney Poovan (AB) cultivar (Table1).

Fusarium wilt was most prevalent in the Grand Nain variety of banana, which had an incidence of 90-95%, followed by the Rasthali variety grown in the Theni district with an incidence of 45 % (Thangavelu *et al.*, 2024). The Fusarium wilt disease incidence ranged from 1.52 to 43.65

Table 1. Incidence of *Fusarium* wilt of Banana major Banana growing villages of Karur district

S. No.	Village name	Name of cultivar	Age of the crop	Latitude	Longitude	Disease incidence (%)
1	Lalapet	Karpooravalli	9	10.95567	78.28320	28.66
2	Neidalur south	Ney Poovan	8	10.81598	78.51492	38.35
3	Neidalur North	Karpooravalli	9	10.93430	78.41257	41.50
4	Vaazhanthur	Ney Poovan	8	10.90130	78.46077	23.58
5	Hiraniyamangalam	Karpooravalli	10	10.85740	78.43540	33.65



Figure 1. Fusarium wilt infected plant of Ney Poovan (AB) cultivar.



Figure 2. Fusarium wilt infected plant of Karpooravalli (ABB) cultivar.

per cent, with 20.41 to 49.57 per cent severity on the Poovan variety grown in Kerala (Lishma *et al.*, 2024). Banana cultivation in the Uttar Pradesh region was threatened with a major loss due to the disease, with an average incidence ranging from 30% to 50% throughout the region (Damodaran *et al.*, 2019).

Symptomatology

The yellowing of leaves was the first initial symptom that arose six months after planting. Later, these leaves hang down around the plant. Longitudinal splitting of the pseudo-stem was observed in 8 and 11 months after planting the Ney Poovan and Karpooravalli cultivars, respectively. The vascular portion of the affected trees showed that brown colour. The affected trees were finally dead **(**Figure 1 and 2**)**.

Yellowing of lower older leaves is the initial symptom, and infected plants frequently develop longitudinal splits on the pseudo-stem just above the soil level. Dead leaves hanging around the pseudo stem, which looks like a skirt, is the usual external symptom (Thangavelu *et al.*, 2020). The yellow colour of leaves spreads from lower leaves to upper leaves, and all the leaves of the banana tree turn yellow (Sangeetha *et al.,* 2023). Cracks are seen from the bottom along the length of the stem, and side shoots appear before the tree dies (Denny *et al.*, 2022).

The affected rhizome appeared as yellow, brown and black colours when cut into cross-section (Ye *et al.*, 2020). Discolouration of the mat when split lengthwise and the affected stem has rotten fish smells are typical symptoms of Panama wilt (Ha *et al.*, 2017).

Effect of different treatments on Fusarium wilt, growth parameters and economics in the Karpooravalli (ABB) cultivar of banana (Field trial 1)

Fusarium wilt incidence

The per cent disease incidence, growth parameters and other economic parameters data of the Karpooravalli variety of banana were presented in Table 2. The results revealed that the minimum incidence of Fusarium wilt was recorded in TO-4 (8.4%), *i.e.*, banana suckers dipping with 0.25% Carbendazim solution for 15 minutes one day before planting and soil application of NRCB microbial consortia 50 gm per plant at the time of planting and then second, fourth and sixth months after planting followed by TO-5(9.25%), *i.e.*, soil drenching with 0.2% solution of Tebuconazole 50% + Trifloxystrobin 25% 75WG at second and fourth month after planting when compared to control plot (39.75%)(Figure 3 to Figure 7).

Table 2. Effect of different treatments on Fusarium wilt, yield parameters and economics in the Karpooravalli (ABB) cultivar of banana

Treatment	Wilt incidence (%)	Bunch weight (Kg)	Number of hands per bunch	Number of fingers per bunch	Yield (t/ ha)	Gross cost (Rs./ha)	Gross income (Rs./ha)	Net income (Rs./ha)	B:C Ratio
TO-1	22.5	16.75	7.6	106.4	25.96	3,63,350	6,49,000	2,85,650	1.78
TO-2	10.7	16.25	8.5	124.5	33.42	3,75,173	8,35,500	4,60,327	2.22
TO-3	14.7	17.75	7.9	110.6	30.40	3,69,250	7,60,000	3,90,750	2.05
TO-4	8.40	19.80	9.0	142.4	36.53	3,76,190	9,13,250	5,37,060	2.42
TO-5	9.25	18.80	8.7	130.5	34.12	3,77,175	8,53,000	4,75,825	2.26
TO-6	39.75	15.25	7.2	93.60	20.23	3,15,500	5,05,750	1,90,250	1.60
SE(d)	**0.35**	**0.32**	**0.14**	**2.08**	**0.57**	-	-	-	-
CD @ 1%	**0.74**	**0.67**	**0.30**	**4.38**	**1.19**	-	-	-	-



Figure 3. Soil application of NRCB microbial consortia at the time of planting.



Figure 5. Soil application of NRCB microbial consortia at fourth month after planting.



Figure 4. Soil application of NRCB microbial consortia at second month after planting.



Figure 6. Soil application of NRCB microbial consortia at sixth month after planting.



Figure 7. Soil application of TNAU strains of *Trichoderma viride and Bacillus subtilis*



Figure 8. Best treatment plot.

The results are in line with the studies on incidence of Fusarium wilt which was effectively slowed down by banana plants treated with native rhizobacterial isolates of *Bacillus* and *Paenibacillus,* resulting in a 50% reduction in incidence under pot culture conditions (Pankaj *et al.*, 2025). The minimum Fusarium wilt incidence rate of 8.25% was observed in the field with soil application of NRCB strains of *Trichoderma viride* and *Paecilomyces lilacinus,* each at 10 g per plant as basal, second, fourth and sixth months after planting (Anand *et al.*, 2022).

Yield and growth parameters

The maximum banana yield was recorded in TO-4 with 36.53 t/ha, followed by TO-5 with 34.12 t/ha (Figure 8). The untreated control plots recorded the lowest yield of 20.23 t/ha. The banana plants in TO-4 showed the highest number of hands/bunch (9), No. of fingers/bunch (142.4) and Bunch weight (19.8 kg), followed by TO-5 showed that No. of hands/bunch (8.7), No. of fingers/bunch (130.5) and Bunch weight (18.8 kg), and compared to the control plot showed that the lowest No. of hands/bunch (7.2), No. of fingers/bunch (93.6) and Bunch weight (15.25 kg).The maximum B: C ratio 2.42 was obtained by the treatment TO-4 followed by TO-5, *i.e.*, 2.26 (Table 2).

Soil application of NRCB strains of *Trichoderma viride* and *Paecilomyces lilacinus* each at 10 g per plant four times at a two-month interval from planting onwards, increased the yield up to 35.75 t/ha (Anand *et al.*, 2022). The banana plants treated with soil application of *Pseudomonas* sp regulated the plant growth and suppress the phytopathogens' growth through production of phytoharmones like auxins, gibberellins, Indole-3-acetic acid, secondary metabolites (flavonoids) and enzymes like aminocyclopropane-1-carboxylate, phenylalanine ammonia-lyase (Sah *et al.*, 2021). Soil application of *Paenibacillus* strain SVS02 increase the plant growth through phosphate mineralisation, biofilm formation, production of hydrolytic enzymes, hydrogen cyanide, acetoin, and IAA (Pankaj *et al.*, 2025).

Effect of different treatments on Fusarium wilt, Growth parameters and economics in the Ney poovan (AB) cultivar of banana (Field trial 2)

The percentage disease incidence, growth parameters and other economic parameters data of the Ney Poovan cultivar of banana were presented in Table 3. The results revealed that the minimum incidence of Fusarium wilt was 8.9 % in TO-4, followed by 10.27 % that was observed in TO-5 when compared to the control plot (40.90%).

The growth of *the Foc* TR4 strain B2 under pot culture conditions can be effectively inhibited by soil application of both *Trichoderma viride* and *T. harzianum*, which are multiplied in sand maize medium, using 50g per pot (Shukla *et al.*, 2024). The soil application of equal volumes of liquid fermentation cultures of Paenibacillus terrae, Burkholderia cepacia, Bacillus amyloliquefaciens, and Trichoderma harzianum significantly reduced the incidence of banana fusarium wilt, with a control efficiency of 60.53% (Du *et al.*, 2024). The *Streptomyces* strain XY006 effectively suppressed the incidence of Fusarium wilt of banana (FWB), with a bio-control efficacy of up to 87.7% under pot culture conditions (Wang *et al.*, 2023).

Yield and growth parameters

The maximum banana yield was recorded in TO-4 with 33.02 t/ha, followed by TO-5 with 31.32 t/ha. The untreated control plots recorded the lowest yield of 17.55 t/ha. The banana plants in TO-4 showed the highest number of hands/

Table 3. Effect of different treatments on Fusarium wilt, yield parameters and economics in the Ney Poovan (AB) cultivar of banana

Treatment	Wilt incidence (%)	Bunch weight (Kg)	Number of hands per bunch	Number of fingers per hand	Yield (t/ ha)	Gross cost (Rs./ha)	Gross income (Rs./ha)	Net income (Rs./ha)	B:C Ratio
TO-1	21.60	12.31	7.8	114.80	25.52	3,60,100	7,42,560	3,82,460	2.06
TO-2	10.45	13.15	8.1	128.70	31.38	3,70,125	9,06,640	5,36,515	2.44
TO-3	14.81	13.87	7.9	125.50	30.49	3,63,750	9,09,720	5,45,970	2.50
TO-4	8.90	14.38	8.5	134.50	33.02	3,72,200	10,08,560	6,36,360	2.70
TO-5	10.27	13.91	8.2	129.25	31.32	3,74,100	9,60,960	5,86,860	2.56
TO-6	40.90	10.80	6.2	97.80	17.55	3,02,500	4,91,400	1,88,900	1.62
SE(d)	**0.35**	**0.24**	**0.14**	**2.21**	**0.60**	**-**	**-**	**-**	**-**
CD @ 1%	**0.75**	**0.51**	**0.29**	**4.67**	**1.26**	**-**	**-**	**-**	**-**

bunch (8.5), No. of fingers/bunch (134.5) and Bunch weight (14.38 kg), followed by TO-5 showed that No. of hands/ bunch (8.2), No. of fingers/bunch (129.25) and Bunch weight (13.9 kg), and compared to the control plot showed that the lowest No. of hands/bunch (6.2), No. of fingers/bunch (97.8) and Bunch weight (10.8 kg). The maximum B: C ratio, 2.70, was obtained by the treatment TO-4 followed by TO-5, *i.e.*, 2.56 (Table 3).

Many PGPRs produce plant hormones such as auxins that substantially promote root growth, root architecture and nutrient uptake and also help in coping with biotic and abiotic stress (Ranjan *et al.*, 2025). The rice seedlings treated with consortia of *Bacillus aryabhattai* and different strains of *Bacillus megaterium* with catalase activity showed improvement in dry biomass, shoot and root length (Saeed *et al.*, 2023). The host plant used PGPR as a nitrogen source to produce ammonia and increase overall growth (Bhattacharyya *et al.*, 2020).

CONCLUSION

The NRCB microbial consortia consisting *Trichoderma asperellum* and *Bacillus flexus* isolated from the native rhizosphere soil of banana significantly reduced Fusarium wilt disease, and the treated plants exhibited a larger bunch size and a higher number of fruits. NRCB Bio consortia and Tebuconazole 50% Trifloxystrobin 25% 75WG (Nativo) fungicide have the same effect on yield and disease control in banana crops. Biocontrol agents have both the action of suppressing disease and promoting plant growth, while chemicals only have the action of suppressing disease. It is concluded that the farmers can utilize the TO-4, *i.e.*, Corm treatment with Carbendazim solution at 0.25% one day before planting followed by soil application of NRCB microbial consortia at 50 gm per plant at the time of planting, second, fourth and six months after planting for effective management of *Fusarium* wilt, which results in sustainable yield and economic returns.

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