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Fusarium Wilt in Pigeonpea (*Cajanus cajan* L.) in Odisha's Western Undulating Zones: An Integrated Approach

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Field experiments were conducted with pigeonpea (*Cajanus cajan* L.)crop varietyPRG-176 (Ujwala) at Regional Research and Technology Transfer Station, Bhawanipatna, OUAT, Odisha during the Kharif seasons of 2023-24 and 2024-25, evaluating the effectiveness of biological, chemical, and integrated management techniques on Fusarium wilt disease severity.Results indicated that combination of*Trichoderma viride*seed treatment (ST) and soil application (SA) with neem cake and enriched FYM produced the best outcomes, with the lowest PDI (5.21%), highest yield (14.92 q/ha), and the highest incremental cost-benefit ratio (ICBR) of 1:11.80. This holistic plant and soil nutrient enrichment combined with biocontrol strategy enhanced crop productivity and yield stability, leading to improved cost–benefit ratios and higher net economic returns compared with conventional practices.The results offer a sustainable foundation for pigeonpea management of Fusarium wilt especially in Odisha's western undulating regions.

Keywords : Bio-agents, *Fusarium udum*, Pigeonpea, *Trichoderma viride,* Wilt

INTRODUCTION

Pigeonpea *[Cajanus cajan (L.) Millsp.]* is a major pulse crop of the semi-arid tropics, with India contributing nearly 90% of its global area and production (Sarkar *et al* 2020; Jeevarathinam and Chelladurai 2020). The crop is treasured for its high protein content (20–22%) and its function in biological nitrogen fixation, making it integral to rainfed and low-input farming systems. However, the crop productivity is severely hindered by Fusarium wilt, caused by the soil-borne fungus *Fusarium udum* (syn. *F. oxysporum* f. sp. *udum*), which can impose yield losses of 67–100% in susceptible cultivars. This wilt diseaseis prevalent across all major pigeonpea cultivating regions.

Wilt symptom is characterized by vascular discoloration, wilting, and purple stem banding, particularly at flowering and podding stages(Ghante *et al* 2018; Naik *et al* 2022; Reddy *et al* 2024).Fusarium wilt is well known for its lengthy survival period in the soil, which often devalues the efficacy of traditional crop rotation and chemical control strategies. The income of agrarian communities is likely to be compromised by the severe yield loss brought about by the yellowing, wilting, and death of infected plants (Pande *et al*. 2013). Rising disease incidence, together with high pathogenic variability and multiple physiological races, poses a serious challenge to pigeonpea cultivation underscoring the need for durable resistant cultivars and eco-friendly management strategies (Ghante *et al.* 2018; Naik *et al*. 2022;Ravikumara *et al* 2022; Reddy *et al*. 2024).Fusarium wilt disease is largely controlled with fungicides, which not only develop resistance in disease causing pathogens but also have deleterious effects on human health and the environment. Odisha's western undulating zones constitutes rainfed soils with

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high pathogen variability makingFusarium wilt almost endemic where yield losses potentially reach 30–100% depending on crop stage (Kumar *et al*. 2021). Integrated management strategies appropriate to such regions combines wilt resistant or locally adapted cultivars, seed treatment and soil application of biocontrols (e.g. *Trichoderma spp., Pseudomonas/Bacillus*), organic amendments such as neem cake, and limited fungicide use to suppress diverse local isolates and support yields under smallholder conditions (Ghante *et al*. 2018). These approaches not only seek to control the pathogen but also increase soil health and crop yield in a sustainable way. Biological agents such as *Trichoderma viride* and *Pseudomonas fluorescens* have been effective in the suppression of soil-borne pathogens by antagonism and competition, while organic amendments like neem cake and enriched farmyard manure (FYM) help in a balanced soil community and enhanced vigor of plants (Harman*et al.* 2004; Choudhary 2023; Haque *et al*. 2025).Selection of *Trichoderma* and *Pseudomonas fluorescens* as biocontrol agents is based on their complementary modes of action.*Trichoderma* suppresses *Fusarium* via mycoparasitism, competitive exclusion, production of antifungal metabolites, and induction of plant defenses. *Pseudomonas fluorescens* inhibits pathogens by producing antibiotics, siderophores, and activating systemic resistance. Combined use enhances disease control, reduces wilt incidence, and increases plant growth and defense enzymes in crops (Rajeswari 2019; Reddy *et al*. 2024).

Recent trends in Fusarium wilt management in pigeonpea highlight the use of nanotechnology-based fungicides (Sikka *et al.* 2021). Metagenomics and endophytic microbial consortia are being leveraged to understand and manipulate soil microbiomes for enhanced plant defense (Tyagi *et al*. 2025). Induced systemic resistance (ISR) through beneficial rhizobacteria is gaining traction as a sustainable strategy (Ravikumara *et al.* 2017). Climate-smart models and mobile-based advisory tools are supporting predictive disease management in real time (Dhavale *et al*. 2025). Additionally, participatory research approaches, including farmer field schools, are facilitating the local validation and adoption of integrated disease management modules (Yohane *et al.* 2021). In spite of such progress, a need still exists for locally tested, cost-effective management packages that are adoptable by farmers (Odeny, 2007; Pande *et al.* 2012). The present work was planned to fill this gap in the form of assessing a set of IDM strategies for managing Fusarium wilt of pigeonpea under field conditions in western undulating regions of Odisha. Hence, present investigation specifically evaluated the efficiency of various biological, chemical, and integrated treatments,to determine the best and farmer-friendly method of controlling this persistent disease in terms of both agronomic performance and economic returns.

MATERIALS AND METHODS

The field experiment was conducted at the Regional Research and Technology Transfer Station, Bhawanipatna, Odisha University of Agriculture and Technology, Odisha, during the Kharif seasons of 2023-24 and 2024-25 to evaluate the impact of different chemical fungicides, organic amendments and biocontrol agents on disease severity and yield parameters under natural epiphytotic conditions for Fusarium wilt of pigeonpea.The trial was conducted withpigeonpea variety PRG-176 (Ujwala) which is an indeterminate, semi spreading, mid-early duration variety (150-160 days), suitable to low rainfall regions and light soils, sown in first week of August with aspacing of 45 cm and 30 cm between row and plant.The field experiment was laid out in a randomized block design with seven treatments and three replications. Each treatment plot measured 3.0 m × 2.4 m (7.2 m²) with total seven treatments, each replicated thrice, adopted in plot size of 11.4m×19.8m. *viz.,*Seed treatment(ST) with *Trichoderma viride* @10 g/kg + Soil application(SA) with *Trichoderma viride* @ 2.5 Kg/ha +100 Kg/ha enrichedFYM at sowing;(ST) *Pseudomonas fluorescens* @ 10 g /kg + (SA) *P. fluorescens* @ 2.5 Kg/ha +100 Kg of enriched FYM at sowing;(*ST) Trichoderma viride* @10 g/kg + (SA) *Trichoderma viride* @ 2.5 Kg/ha +100 Kg/ha enriched FYM at sowing + Neem cake @ 2.5q/ha;(ST) *Pseudomonas fluorescens* @ 10 g /kg + (SA) *P. fluorescens* @

2.5 Kg/ha +100 Kg of enriched FYM at sowing + Neem cake@2.5q/ha;(ST) Carboxin 37.5%+ Thiram 37.5% WS @2g/kg + Soil drenching (SD) of Metalaxyl 4%+Mancozeb 64% WP@2.5g/l ;(ST) Carboxin 37.5%+ Thiram 37.5% WS @2g/kg + (SD) Tebuconazole 25.9%EC @1.5ml/l A spacing of 60 cm was maintained from plot border and between each replication column whereas 30 cm spacing was maintained between treatment plots per replication to avoid inter-plot and inter-replication interference. Based on this layout, the total experimental area occupied by the trial was 225.72 m², inclusive of plots, treatment gaps, replication gaps, and borders.A recommended dose of fertilizers was applied and irrigation ensured proper seed germination. Thinning and gap filling operations were carried out ten days after sowing to maintain uniform plant population.The statistical analysis of Randomized Block Design was carried out as per the procedure given by Fisher and Yates (1963).

Observations on wilt disease incidence were recorded from total infection per treatment plot (7.2 m²).Wilt incidence was recorded at threecritical crop growth stages*viz.,* flowering(100 ± 10 DAS), pod-filling(120 ± 10 DAS), and maturity stage (140 ± 10 DAS) and then averaged. Yield parameters were measured in quintals per hectare (q/ha).Additionally, an economic analysis was performed by calculating the incremental cost-benefit ratio (ICBR) for each treatment, providing insight into the profitability and practical viability of the different disease management approaches. After, threshing and winnowing seed weight of each treatment per replication was calculated in quintal per hectare by using net plot yield data. Normality of data was checked by Shapiro–Wilkins test and OPSTAT program was used for ANOVA (Sheoran *et al.* 1998).Percentage disease incidence (PDI) was calculated using the formula-

$$\text{Per cent disease incidence} = \left(\frac{\text{Total no. of diseased plants}}{\text{Total no. of plants sampled}}\right) \times 100$$

The infected disease specimens particularly the roots with lower stem of pigeonpea were collected from Regional Research and Technology Transfer Station, Bhawanipatna, OUAT, Odisha, during crop seasons of 2023-24 and 2024-25 and the pathogens were observed under microscope.

RESULTS AND DISCUSSION

The pooled data presented in Table 1. as well asthe PDI variation provided in Fig. 1revealed that during 2023-24 and 2024-25 Fusarium wilt severity varied from a minimum Percent disease index (PDI) of 5.21% for the treatment detail: **(**ST) *Trichoderma viride* @10 g/kg + (SA) *Trichoderma viride* @ 2.5 Kg/ha +100 Kg/ha enriched FYM at sowing + Neem cake @ 2.5q/ha, tomaximum of (21.18%) for the control plot. The variation in yield represented by Figure 2.registered lowest yield (8.22 q/ha) for control plot and highest of (14.92 q/ha) in treatment which showed the lowest Percent Disease Index (PDI). The analysis of variance (ANOVA) represented by Table 2. revealed that the calculated F value for PDI (%)

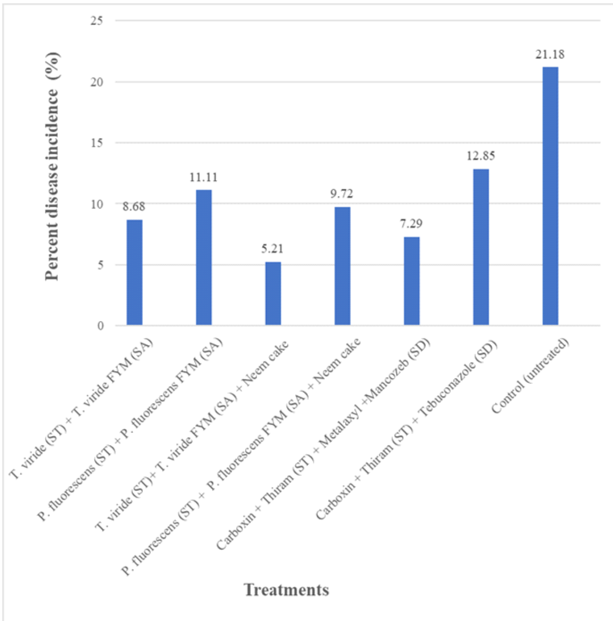

Fig 1: Graphical representation of Precent disease incidence (%) against Treatments. ST=Seed treatment, SA= Soil application, SD=Soil drenching, *T. viride*=*Trichoderma viride*, *P. fluorescens*= *Pseudomonas fluorescens,* FYM=Farm yard manure

(32.52) and yield (q/ha) (35.89), exceeded the tabulated value at 6 and 14 degrees of freedom ($F_{0.05} \approx 2.85$), indicating that it is likely that various treatments does have a significant effect onPercent disease index (PDI) and Yield (Kg/ha).Other treatments showed intermediate performance, with moderate yields (9.21–13.82 q/ha) and PDI values ranging from 12.85% to 7.29%.

The economic evaluation of treatments under study(Table 1) revealed distinct differences in yield

Table 1: Descriptive statistics of efficacy of various treatments on Fusarium wilt disease of pigeon pea (pooled 2023-24 and 2024-25)

Treatment Description	Variables under study				Economic Analysis of Pooled data for 2023-24 and 2024-25			
	PDI (%)	DDOC (%)	Yield (q/h)	YIOC (%)	Yield Incr. (q/ha)	Total Cost (Rs/ha)	Net Profit (Rs/ha)	ICBR
(ST) *Trichoderma viride* @10 g/kg + (SA) *Trichoderma viride* @ 2.5 Kg/ha +100 Kg/ha enriched FYM at sowing	8.68	59.02	12.33	50.04	5.16	3298	32845	01:10.00
(ST) *Pseudomonas fluorescens* @ 10 g /kg + (SA) *P. fluorescens* @ 2.5 Kg/ha +100 Kg of enriched FYM at sowing	11.11	47.54	9.61	16.89	2.29	2931	13075	01:04.50
(ST) *Trichoderma viride* @10 g/kg + (SA) *Trichoderma viride* @ 2.5 Kg/ha +100 Kg/ha enriched FYM at sowing + Neem cake @ 2.5q/ha	5.21	75.41	14.92	81.5	7.43	3790	48186	01:12.70
(ST) *Pseudomonas fluorescens* @ 10 g /kg + (SA) *P. fluorescens* @ 2.5 Kg/ha +100 Kg of enriched FYM at sowing + Neem cake@2.5q/ha	9.72	54.1	11.26	37.02	4.09	3652	25001	01:06.80
(ST) Carboxin 37.5%+ Thiram 37.5% WS @2g/kg + (SD) of Metalaxyl 4%+Mancozeb 64% WP@2.5g/l	7.29	65.57	13.82	68.13	6.27	3330	40591	01:12.20
(ST) Carboxin 37.5%+ Thiram 37.5% WS @2g/kg + (SD) Tebuconazole 25.9%EC @1.5ml/l	12.85	39.34	9.21	12.02	1.17	2259	5954	01:02.60
Control (untreated)	21.18	0	8.22	0	0	-	-	-
CD (0.05)	2.01		1.19					
SE (m)	0.97		0.58					
SE (d)	1.29		4.33					
C.V.	25.57		23.64					
Shapiro Wilkins test for normality	(W) 0.92 (P) 0.92		(W) 0.91 (W) 0.90					

Abbreviations: ST=Seed Treatment, SA= Soil application, SD= Soil drenching; DDOC=Disease Decrease Over Control; YIOC= Yield Increase Over Control; ICBR= Incremental Cost Benefit Ratio

gains, cost of cultivation, net profitability, and incremental cost–benefit ratio (ICBR).The most profitable treatment registered a yield increase of 7.43 q ha^{-1} with an additional cultivation cost of qha^{-1} 3,790 qha^{-1}, giving the highest net profit of qha^{-1} 48,186 qha^{-1} and an ICBR of 1:12.70, showing superior economic viability. The least responsive treatment showed only 1.17 qha^{-1}

yield improvement at a cost of qha^{-1} 2,259 qha^{-1}, registering a net profit of qha^{-1} 5,954 qha^{-1} and an ICBR of 1:2.6, advocating minimal economic justification. The control treatment did not register any yield increase nor generate additional costs, profits, or ICBR.

Numerous studies consistently validate that integrated disease management modules combining *Trichoderma* seed treatment with soil application of enriched organic manures cause the lowest disease incidence and highest yields, surpassing conventional chemical seed dressings based on carboxin + thiram or similar fungicides (Vani and Srilatha 2024;). In groundnut combined seed and soil application of *Trichoderma* with vermicompost reduced stem rot incidence by approximately 70–80% and produced higher pod yields and benefit–cost ratios than carboxin + thiram–based modules (Hotkar *et al*. 2025). Similarly, in turmeric, integrated application of *T. viride* with FYM and neem cake reduced soil-borne disease incidence nearly threefold and notably enhanced yield and B:C ratio against copper oxychloride drenching alone (Vani and Srilatha, 2024).

Similar trends have been described for Fusarium wilt and other soil-borne diseases, where organic manures inoculated with antagonistic microorganisms such as *Trichoderma* and *Bacillus* alters the soil microbiome to a disease-suppressive state, following stable reduction of wilt incidence across seasons (Akanmu *et al*. 2021; Tang et al. 2023). The efficacy of *Trichoderma* spp. is credited to several mechanisms, which includes mycoparasitism, contest for nutrients and space, and stimulation of systemic resistance in host crop plants (Harman *et al*. 2004; Mukherjee et al. 2013). The inclusion of neem cake fosters disease suppression through azadirachtin and other bioactive metabolites, while also prospering the soil health. Similarly, composted FYM is supplements microbial activity and nutrient availability, mutually contributing to the development of a suppressive soil environment (Hotkar *et al.* 2025; Haque *et al.* 2025).

In contrast, continuedapplication of chemical fungicides time and again leads to the development of resistant pathogen populations and establishes risks of environmental contamination and adverse effects on non-target beneficial microorganisms (Goswami and Kistler 2005; Popp *et al*. 2013; Janssen *et al*. 2024). Recent advances further strengthen this approach.A novel *Trichoderma viride* DS2 dustable powder formulation (1% w/w) exhibited superior efficacy against *Fusarium oxysporum* f. sp. *ciceris*, recording only 3.33% wilt incidence and 93.33% seed germination at the recommended dose, and outperforming both carbendazim (50% WP) and talc-based formulations in terms of bio-efficacy and seedling vigor (Pradhan et al. 2022). Integrated application of biocontrol agents and organic amendments, consequently offers an environmentally friendly alternative that boosts long-term soil fertility, plant vigor, crop productivity and economic returns making it remarkably suitable for resource-poor farmers (Behera *et al.* 2024; Vani and Srilatha 2024; Hotkar *et al*. 2025). However, disease expression and biocontrol performance, particularly against Fusarium wilt, are strongly

Table 2 : One-way ANOVA for PDI and Yield (q/ha)

		PDI			Yield (q/ha)		
Source of Variation	Degrees of Freedom (df)	Sum of Squares (SS)	Mean Square (MS)	F Value	Sum of Squares (SS)	Mean Square (MS)	F Value
Treatments	6	183.52	30.59	32.52	70.34	11.72	35.89
Replication	2	2.97	1.48	1.74	1.08	0.54	1.86
Error	12	10.2	0.85		3.49	0.29	
Total	20	196.69			74.91		

influenced by soil properties, pathogen variability, and environmental conditions. Multi-location evaluations are therefore essential to identify stable and broadly effective management strategies, as well as to develop location-specific

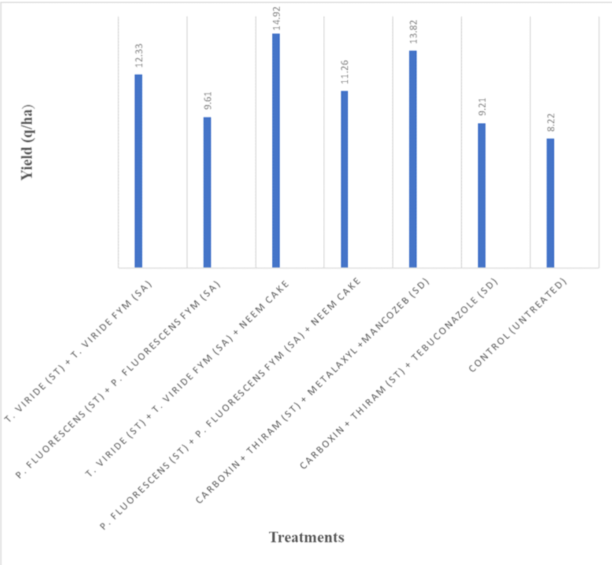

Fig. 2. Graphical representation of Yield(q/ha) against Treatments. ST=Seed treatment, SA= Soil application, SD=Soil drenching, *T. viride=Trichoderma viride*, *P. fluorescens= Pseudomonas fluorescens,* FYM = Farm yard manure

recommendations for diverse agro-ecologies (Saxena, 2010; Sharma *et al.* 2016).

CONCLUSION

To summarize, the findings of present investigation concluded that while chemical seed treatment and soil drenching are effective, bio - control with *Trichoderma* combined with neem cake and enriched FYM can deliver equal or better disease suppression, higher yield, and superior economic and sustainability outcomes, particularly in rainfed and fragile agro ecosystems.

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DECLARATION

Conflict of interest.Authors declare no conflict of interest.

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