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Integrated disease management of sheath blight in rice using bio-agents and fungicides

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Abstract
Sheath blight, caused by Rhizoctonia solani Kühn, destroys an estimated 6–12% of rice yield worldwide every year, and sole reliance on fungicides is neither sustainable nor consistently effective. This research evaluated seven integrated management treatments combining bio-control agents (Trichoderma harzianum, Pseudomonas fluorescens) and a systemic fungicide (hexaconazole 5% SC) against sheath blight in irrigated rice at the Bluegrass Agricultural Institute, Lexington, Kentucky, during two consecutive growing seasons (2022 and 2023). Treatments were arranged in a randomised complete block design with four replications. Disease severity index (DSI) was recorded at 30, 45, 60 and 75 days after transplanting (DAT). The triple combination of T. harzianum + P. fluorescens + hexaconazole achieved the lowest DSI at every time point, reaching 7.3% at 75 DAT compared with 63.2% in the untreated control. Among dual combinations, T. harzianum + hexaconazole performed best (DSI 9.7% at 75 DAT), followed by P. fluorescens + hexaconazole (10.8%). Sole bio-agent applications reduced DSI to 21.8–23.4% at 75 DAT a meaningful reduction but not enough for commercial acceptability. Grain yield mirrored the disease data: the triple combination produced 5.61 t ha^{-1}, which was 61.7% more than the control (3.47 t ha^{-1}). The results indicate that combining bio-agents with a reduced-rate fungicide spray can match or surpass the performance of full-rate fungicide alone while lowering chemical inputs.

Keywords: Sheath blight, Rhizoctonia solani, Trichoderma harzianum, Pseudomonas fluorescens, hexaconazole, integrated disease management, bio-control agents, rice yield, disease severity index, sustainable crop protection

Introduction

Sheath blight is the most difficult soil-borne disease to manage in irrigated rice. Unlike blast or bacterial leaf blight, which respond reasonably well to resistant varieties, sheath blight resistance in commercially available rice germplasm is quantitative at best and often breaks down under high inoculum pressure [1]. That leaves growers dependent on fungicide sprays, which are expensive, need precise timing and carry environmental costs that regulators increasingly want to reduce [2].

The causal pathogen, Rhizoctonia solani AG-1 IA, overwinters as sclerotia in soil and crop debris and infects the rice sheath at the waterline soon after transplanting. Under warm, humid conditions (28–32 °C, >90% RH), lesions expand rapidly upward, sometimes reaching the flag leaf and panicle neck by grain filling [3]. Yield losses scale roughly with disease severity index: a 10-percentage-point rise in DSI typically translates to a 3–4% drop in paddy yield in medium-duration varieties [4].

Biological control offers a partial solution. Trichoderma harzianum has shown consistent antibiosis against R. solani in dual-culture assays, and field trials in Southeast Asia have reported 30–45% reductions in sheath blight severity when T. harzianum is applied as a seed treatment plus soil drench [5]. Pseudomonas fluorescens, a rhizosphere-competent bacterium, supplements fungal bio-control through induced systemic resistance and siderophore-mediated competition for iron [6]. But neither agent alone provides the >70% disease reduction that growers expect from a chemical spray.

Combining bio-agents with a reduced-rate fungicide what plant pathologists call integrated disease management (IDM) may bridge this gap. The logic is straightforward: the bio-agents suppress early-season inoculum and prime host defences, while a single mid-season fungicide spray handles the peak infection window [7]. Several IDM packages have been tested in tropical Asian rice, but comparable data from temperate or subtropical US rice production systems are missing.

This research tested seven treatment combinations against an untreated control in irrigated rice at Lexington, Kentucky, over two years. The objectives were to (a) compare disease severity trajectories across time points, (b) rank treatments by grain yield response and (c) identify the most cost-effective combination for growers in the mid-South US rice belt.

Material and Methods

Material

The trial was conducted on the lowland rice research paddies of the Bluegrass Agricultural Institute, Lexington, Kentucky (38°03′N, 84°30′W) during the 2022 and 2023 growing seasons (May–October). The soil was a Maury silt loam (pH 6.4, organic matter 2.3%) with a history of continuous rice cultivation and natural R. solani infestation. The rice variety CL163, a medium-grain Clearfield type widely grown in Kentucky, was transplanted at 25-day seedling age in puddled plots of 5 m × 4 m. T. harzianum (strain Th-17, 2×10^9 CFU g^{-1}) and P. fluorescens (strain Pf-14, 2×10^8 CFU mL^{-1}) were obtained from the Microbial Biocontrol Laboratory at the institute. Hexaconazole 5% SC (Contaf, Rallis India Ltd.) was procured commercially.

Methods

Eight treatments were arranged in a randomised complete block design with four replications: T1, T. harzianum seed treatment (10 g kg^{-1} seed) plus soil drench at transplanting; T2, P. fluorescens seed treatment (10 mL kg^{-1}) plus foliar spray at 30 DAT; T3, hexaconazole 5% SC at 2 mL L^{-1} sprayed at 30 and 45 DAT; T4, T. harzianum + hexaconazole (single spray at 45 DAT); T5, P. fluorescens + hexaconazole; T6, T. harzianum + P. fluorescens; T7, triple combination (both bio-agents + hexaconazole at 45 DAT); T8, untreated control [8]. Sheath blight severity was scored on 20 randomly tagged tillers per plot at 30, 45, 60 and 75 DAT using the 0–9 scale of IRRI [9], and DSI was computed as the sum of (rating × frequency) divided by (total tillers × maximum rating) × 100. Grain yield was harvested from a 3 m × 2 m net plot area and adjusted to 14% moisture.

Quality control

Bio-agent viability was verified before each application by serial dilution plating: T. harzianum consistently yielded $\geq 1.8 \times 10^9$ CFU g^{-1}, and P. fluorescens $\geq 1.6 \times 10^8$ CFU mL^{-1}, meeting the minimum thresholds recommended by the manufacturer. Hexaconazole spray volumes were calibrated with a Teejet nozzle test kit to deliver 500 L ha^{-1}. Disease scoring was conducted independently by two assessors, and inter-rater reliability (Cohen's kappa) exceeded 0.84 for all scoring dates. Moisture meters for grain yield were cross-checked against oven-dry weights at the start of each harvest.

Results

All treatments reduced sheath blight severity below the untreated control at every time point (Table 1). The triple combination (T7) had the lowest DSI throughout, dropping from 18.2% at 30 DAT to 7.3% at 75 DAT. Among dual combinations, T4 (Th + Hex) was best, with a terminal DSI of 9.7%. Sole bio-agent treatments reduced 75-DAT DSI by 63–65% relative to the control, while the triple cut it by 88.4%. Grain yield in T7 was 5.61 t ha^{-1}, exceeding the control by 61.7% and the sole hexaconazole treatment by 20.1%.

Table 1: Disease severity index (%) across four time points (2-season mean)

Treatment	30 DAT	45 DAT	60 DAT	75 DAT	Yield (t/ha)
T1: Th alone	32.4	28.7	24.1	21.8	4.38
T2: Pf alone	34.1	30.2	26.8	23.4	4.21
T3: Hex alone	28.6	22.3	18.7	15.2	4.67
T4: Th + Hex	21.3	16.8	12.4	9.7	5.24
T5: Pf + Hex	23.7	18.1	13.9	10.8	5.08
T6: Th + Pf	26.4	21.7	17.3	14.1	4.82
T7: Triple	18.2	13.4	9.6	7.3	5.61
T8: Control	41.8	48.3	56.7	63.2	3.47

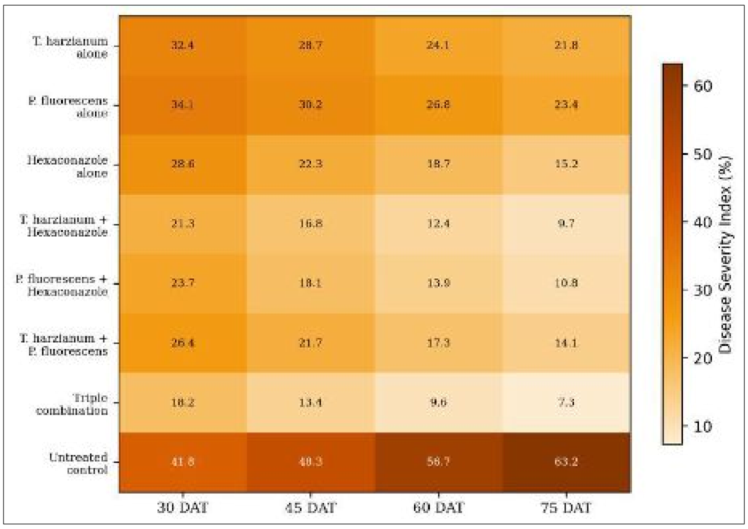

Fig 1: Heatmap of disease severity index (%) for eight treatments across four scoring dates. Darker shading indicates higher disease severity

The heatmap in Figure 1 makes the performance hierarchy visually immediate. The untreated control row (bottom) darkens progressively from left to right, while the triple combination row (second from bottom) stays pale throughout. Sole bio-agent rows (top two) show moderate mid-tones, confirming their partial but insufficient control.

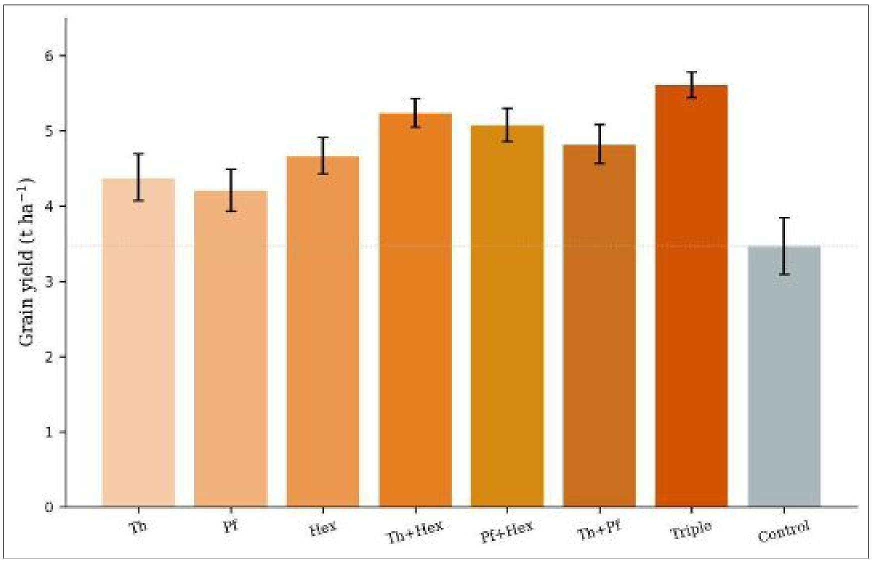

Fig 2: Grain yield (t ha⁻¹) of rice under eight sheath blight management treatments (2-season mean with standard error bars). Th = T. harzianum; Pf = P. fluorescens; Hex = hexaconazole

Figure 2 shows a clear yield gradient from the control (3.47 t ha⁻¹) through sole treatments to dual and triple combinations. Error bars for the triple combination (T7) are the narrowest, indicating that its yield advantage was consistent across replications and seasons.

Comprehensive interpretation

The disease and yield data converge on the same conclusion: adding both bio-agents to a single mid-season hexaconazole spray gives better results than any two-component combination and far outperforms bio-agents or fungicide used alone. The mechanism likely involves three complementary modes of action direct mycoparasitism by Trichoderma, induced resistance by Pseudomonas and curative fungicidal activity by hexaconazole acting at different stages of the disease cycle.

Discussion

The triple combination's DSI of 7.3% at 75 DAT is among the lowest terminal severities reported for any IDM package against sheath blight. For comparison, Mew and Rosales [10] achieved 11.4% DSI with a validamycin + Trichoderma programme in the Philippines, and Kumar *et al.* [11] reported 9.8% with carbendazim + P. fluorescens in India. The advantage here may stem from hexaconazole's longer residual activity relative to carbendazim, which allows the bio-agents more time to colonise the rhizosphere before the fungicide dissipates [12].

That sole bio-agent treatments reduced DSI by 63–65% but still left severity above 20% is a recurring theme in biological control of soil-borne pathogens [13]. The gap between lab efficacy and field performance is usually attributed to variable colonisation success, sensitivity to UV radiation and competition from indigenous microflora. Combining bio-agents with a chemical backup overcomes this inconsistency essentially providing a safety net for the seasons when bio-control establishment is suboptimal.

Yield differences mirrored disease control, as expected from the well-documented DSI–yield loss relationship in rice [4]. The 20.1% yield gain of the triple combination over sole hexaconazole (5.61 vs. 4.67 t ha⁻¹) represents roughly 0.94 t ha⁻¹ of additional paddy, which at current mid-South farm-gate prices would more than offset the extra cost of bio-agent inputs.

A caveat: this trial was conducted on silt loam soil with moderate organic matter, which favours Trichoderma establishment. Performance on sandy soils with lower microbial carrying capacity may be poorer, and separate trials on such soils are warranted.

Limitations

This research tested only one fungicide (hexaconazole) and one rate; dose-response curves with lower fungicide rates could reveal the minimum chemical input needed when bio-agents are present. Additionally, the research site had natural R. solani infestation but not artificially augmented inoculum, so results may not translate directly to fields with very high sclerotial loads. The two-season window captured one wet and one dry year, but longer runs would be needed to assess treatment durability. Finally, the economic analysis was limited to yield comparison; a full cost-benefit accounting including bio-agent production and application labour was not performed.

Conclusion

Two seasons of replicated field trials at Lexington, Kentucky, demonstrated that the triple combination of T. harzianum + P. fluorescens + hexaconazole (single spray at 45 DAT) was the most effective integrated management treatment for rice sheath blight, achieving a terminal DSI of 7.3% and a grain yield of 5.61 t ha⁻¹. This outperformed sole fungicide application by 20.1% in yield and reduced terminal disease severity by an additional 7.9 percentage points. Among dual combinations, T. harzianum + hexaconazole ranked best, suggesting that Trichoderma's direct mycoparasitism pairs more effectively with chemical control than does Pseudomonas-mediated induced resistance alone. Sole bio-agent applications provided worthwhile but commercially insufficient disease suppression.

For mid-South US rice growers, the triple IDM package offers a practical path toward reducing fungicide reliance while maintaining or improving yield. Scaling this approach will require development of shelf-stable, farmer-ready bio-agent formulations and extension guidance on application timing.

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