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BIOLOGICAL CONTROL OF RICE BLAST: A PROMISING STRATEGY FOR SUSTAINABLE AGRICULTURE

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Abstract

Rice blast, caused by *Magnaporthe oryzae*, poses a significant threat to rice cultivation worldwide, particularly in Bangladesh where rice is a major staple cereal. This study explores the biocontrol potential of bacterial isolates against rice blast disease, with an emphasis on *in vitro* and field efficacy. Thirty bacterial isolates from indigenous rice varieties and rhizospheric soils were evaluated using dual culture techniques to assess their antagonistic effects on *M. oryzae*. Six isolates demonstrating significant antifungal activity were further tested in field trials through seed and seedling priming methods. Results indicated that these bacterial isolates significantly reduced leaf blast incidence and severity, with specific isolates (Isolate 2 and Isolate 5) showing notable efficacy. Yield was significantly influenced by bacterial treatments, with seed priming using Isolate 5 (358.20 g/m²) and seedling priming using Isolate 2 (342.98 g/m²) achieving the highest yields, significantly outperforming the control (128.72 g/m²). This study highlights the effectiveness of biocontrol agents in enhancing rice production and offers a sustainable strategy for disease management in rice.

Keywords: *Magnaporthe oryzae*, Rice blast, Biological control, Bacterial isolates

Introduction

Rice blast, caused by the fungal pathogen *Magnapoethe oryzae* (anamorph *Pyricularia oryzae*), stands as one of the most destructive diseases impacting rice cultivation globally. It represents a major challenge to worldwide food security, given that rice serves as the principle dietary staple for over half of humanity (Maurya *et al*., 2024). In Bangladesh rice remains the fundamental food crop and economic mainstay for millions of agricultural households. Approximately 28.82 million acres of Bangladesh farmland are devoted to rice cultivation, generating over 40.70 million metric tons annually (BBS, 2024.) The pathogen demonstrates the capacity to infect rice plants throughout their developmental cycle, from early seedling stages through pre-maturity phage. Disease terminology reflects the specific plant organ affected: foliar infections are termed as leaf blast, stem infections as node blast, while panicle infections are classified as neck blast (first panicle node) or panicle blast. Among these, neck blast causes particularly severe and irreversible damage to crop yields. In Bangladesh, blast disease prevalence and intensity peak during the Boro growing season, when water shortage is more prevalent compared to the Aman season (Hossain *et al*., 2017). Recent years have witnessed an expansion of blast occurrence into previously unaffected

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regions, particularly in northern and northwestern territories of Bangladesh (Mahmud *et al*., 2021). The high-yielding varieties BRRI dhan29 and BRRI dhan28, despite their popularity, exhibit marked susceptibility to blast infection (Anonymous, 2011). Additionally, traditional and improved aromatic rice cultivars cultivated during wet seasons demonstrate vulnerability to blast to neck blast infection (Ali and Fukuta, 2010; Khan *et al*., 2014). Research documents average yield reductions of 28-36% attributable to blast, with localized losses reaching complete crop failure (100%) in severe neck blast outbreak during Boro season (Hossain *et al*., 2017). Current estimates identify 267 distinct physiological races of the blast pathogen within Bangladeshi agroecosystems (Biswas, 2017), indicating escalating disease pressure that may precipitate more severe epidemics. Multiple strategies have been implemented to enhance productivity and mitigate blast-related losses. Breeding resistant rice varieties has achieved limited success, constrained by the pathogen's rapid evolutionary capacity to generate new virulent races and the environmental sensitivity of resistant cultivars. A range of fungicides, including azoxystrobin, carbendazim, and tricyclazole, have been deployed against rice blast, with their effectiveness contingent upon application timing, method, and the emergence of resistant strains (Law *et al*., 2017). However, reliance on these synthetic chemicals raises significant concerns regarding environmental pollution, ecosystem damage, pesticide resistance, and risks to human health through occupational exposure and toxic residues (Chen *et al*., 2019).

Therefore, biological control offers a sustainable and eco-friendly alternative to combat this devastating disease. Biological control of rice blast involves the use of microbial antagonists. Several bacteria and fungi have been identified for their ability to suppress the growth and development of *Magnaporthe oryzae*. These antagonistic organisms control rice blast primarily through the mechanisms of competition, antibiosis, and hyperparasitism (Law *et al*., 2017). Their efficacy in antibiosis is mediated by the production of secondary metabolites such as antibiotics, iron-chelating siderophores and cyanogenic compounds that directly inhibit *Magnaporthe oryzae*. Simultaneously, by colonizing the plant's rhizosphere and phyllosphere, they outcompete the pathogen for essential nutrients and space, thereby limiting its establishment and spread. Considering the above things, the main objectives of this research work were to evaluate the antagonistic activity of some isolated bacteria against rice blast *in vitro* and to assess their biocontrol efficacy against rice blast in the field.

Materials and methods

The study was conducted in the molecular laboratory and field of Plant Pathology Division of Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, Bangladesh.

Bacterial isolates

Thirty selected bacterial isolates were available in the laboratory. Twenty endophytic bacteria were isolated from indigenous rice varieties, namely Nunia, Sadamata, Lalzira, Ajgari, Ashibinni, Malaghoti, Haldebatali, and Ranishail. The seeds of indigenous rice varieties were collected from Plant Breeding Divison, BINA. The remaining ten isolates were obtained from rhizospheric soil collected from various agro-ecological zones (AEZs) across Bangladesh. Surface sterilization of rice seeds was performed through sequential washes with tap water, 70% ethanol for 10 minutes, 1% NaOCl for 1 minute, and 100% ethanol for 5 minutes, with five rinses in sterilized distilled water (SDW) after each step**.** The sterilized seeds were then macerated, serially diluted to 10^{-6}, and 100 µl aliquots were plated onto Luria-Bertani Agar (LBA) and Nutrient Broth Agar (NBA) media, followed by incubation at 25^0C for 48 hours. For rhizosphere samples, bacteria were dislodged from 1 g of roots with adhered soil by vortexing in sterile water, and dilutions (10^{-6}) were plated on LBA and King's B Agar for incubation at 28^0C. From both sources, morphologically distinct colonies were purified through repeated streaking and preserved in 20% glycerol solution for long-term storage at -80^0C.

***In vitro* Antifungal Bioassays**

Thirty bacterial isolates were evaluated for antagonistic activity against *Magnaporthe oryzae* using dual culture assays according to Rabindran and Vidvasekaran (1996). Bacterial Whole Cell Culture (BWC) streaks 3 cm from the edge of Potato Sucrose Agar plates. A 5mm mycelial plug from 7-day old *Magnaporthe oryzae* PDA cultures was placed opposite the bacterial streak in 9 cm diameter Petri dishes. Control plates contained only fungal inoculum. The experiment followed a completely randomized design with three replicates. Control plates were incubated at 28^0C until full mycelial coverage was achieved. Antagonistic activity was assessed by measuring inhibition zone formation and radial mycelial growth reduction. Pathogen growth inhibition (%) was calculated according to the following formula (Rini and Sulochana, 2007).

$$I\ \% = C\text{-}T/C \times 100$$

Where, I = Percentage growth inhibition, C = Growth of pathogen in the control plate (cm) and T= Growth of pathogen in dual cultures (cm).

Field trials

Bacterial strains demonstrating prior antagonistic activity in dual culture assays were selected for further evaluation of their suppressive ability under field conditions. Six bacteria found to be active in the dual-culture assay were named as Isolate 1, Isolate 2, Isolate 3, Isolate 4, Isolate 5, and Isolate 6. One field trials were conducted in the research of field Plant Pathology Division with following treatments: T_1= Seed priming with Isolate 1, T_2= Seed priming with Isolate 2, T_3= Seed priming with Isolate 3, T_4= Seed priming with Isolate 4, T_5= Seed priming with Isolate 5, T_6= Seed priming with Isolate 6, T_7= Seedling priming with Isolate 1, T_8= Seedling priming with Isolate 2, T_9= Seedling priming with Isolate 3, T_{10}= Seedling priming with Isolate 4, T_{11}= Seedling priming with Isolate 5, T_{12}= Seedling priming with Isolate 6, T_{13}= Untreated control seeds. Seeds of the US-2 line available in the Plant Pathology Division, BINA, were used in this experiment. US-2 is a standard susceptible control variety in rice blast research. Its known genetic background, which is devoid of major resistance genes, confers high susceptibility to a broad spectrum of *Magnaporthe oryzae* strains. These seeds were disinfected with 10% sodium hypochlorite (NaOCl) for 30 seconds and then washed five times in double-distilled water. The studied bacteria were then cultured in Luria Bertani (LB) agar (Himedia, Mumbai, India) medium and incubated for 24-48 hours at 32^0C. Subsequently, the surface-sterilized seeds were soaked separately in inoculum solutions adjusted to OD 1.0 (at 600 nm with a spectrophotometer) at room temperature for 24 hours (Bahmani *et al.,* 2016). For root colonization and control treatments, seeds were soaked in sterilized distilled water. After soaking, seeds were dried back to their original moisture content and covered with a gunny bag for better germination. After germination, seeds were sown separately in a previously prepared seedbed. Forty-day-old seedlings were soaked in bacterial inoculum solutions adjusted to OD 1.0 (at 600 nm with a spectrophotometer) at room temperature for 24 hours for root colonization. Treated and untreated seedlings were then transplanted into the field. The experiments were conducted in a randomized block design with three replications. The unit plot size was 1.0m x 1.0m, with distances between lines and hills being 20 cm and 15 cm, respectively. Fertilizer applications followed the guidelines of the Fertilizer Recommendation Guide (BARC, 2018), with conventional cultivation practices being observed. Growth conditions were regulated to enhance blast disease occurrence. For half of the experimental plants, only seed treatments were administered, whereas the remaining half underwent root colonization procedure. Both treatment groups received three foliar applications of bacterial suspension (500 ml/m^2) at 30, 40 and 50 days after transplanting (DAT), with the control group renaming untreated. Infection was triggered by applying a spore suspension of *M. oryzae* (50,000 conidia/ml), prepared using the method outlined by Mackill and Bonman (1986). To promote disease development, the entire field was covered with a polythene sheet to maintain high humidity. Foliar blast symptoms were evaluated 10 days of post-inoculation, while panicle blast assessments were conducted at heading maturity. For each treatment, ten randomly chosen rice hills were inspected for foliar lesions and diseased panicles. Foliar blast intensity was graded using the International Rice Research Institute's (IRRI, Manila, Philippines) standardized 0–9 disease rating scale (IRRI, 1996) as presented in Table 1. Panicle blast incidence was calculated by recording both total and infected panicle counts per hill. The data gathered were processed using RStudio analytical software.

Table 1. Disease rating scale used for leaf blast disease (SES, IRRI, 1996)

Scale	Description
0	No lesion observed
1	Small brown specks of pin point size
2	Small roundish to slightly elongated, necrotic gray spots, about 1-2 mm in diameter, with a distinct brown margin. Lesions are mostly found on the lower leaves
3	Lesion type same as in 2, but significant number of lesions on the upper leaves
4	Typical susceptible blast lesions, 3 mm or longer infecting less than 4% of leaf area
5	Typical susceptible blast lesions of 3 mm or longer infecting 4-10 % of the leaf area
6	Typical susceptible blast lesions of 3 mm or longer infecting 11-25 % of the leaf area
7	Typical susceptible blast lesions of 3 mm or longer infecting 26-50% of the leaf area
8	Typical susceptible blast lesions of 3 mm or longer infecting 51-75% of the leaf area; many leaves are dead
9	Typical susceptible blast lesions of 3 mm or longer infecting more than 75% leaf area affected

Results and discussion

Thirty bacterial isolates were evaluated *in vitro* for their antagonistic activity, and only six of these isolates were tested in field conditions against rice blast.

Antifungal Bioassays

Of the thirty bacterial isolates tested, six exhibited growth inhibition in dual culture assay (Figure 1). Control shows a steady increase in mycelial growth over 15 days, reaching the highest value of 6.23 cm (Table 2). Generally, bacterial isolates show lower mycelial growth compared to control, indicates inhibition. Isolate 2 is particularly effective, especially at later stages (10 and 15 days), with significantly lower growth (1.40 cm and 1.43 cm) compared to the control. Isolates 1, 3, 4, 5, and 6 also show inhibitory effects but with varying degrees of effectiveness. Most isolates significantly reduce growth at early stages (2 and 4 days). The inhibition of mycelial growth by bacterial isolates is statistically significant (S) at 2 and 4 days and again at 10 and 15 days, indicating effective control by the isolates during these periods. Non-significant (NS) results at 6 and 8 days suggest that differences between treatments might not be pronounced during this period.

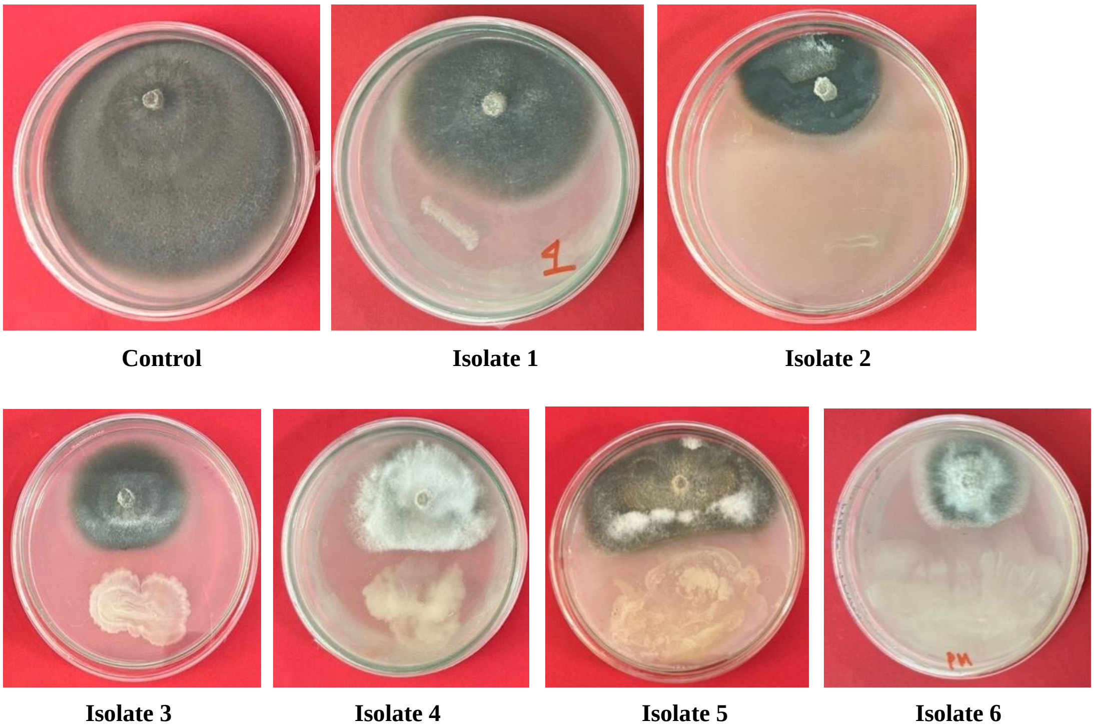

Fig. 1: Antagonistic bacteria suppress the growth of *Magnaporthe oryzae* in Potato Sucrose Agar media after 15 days of incubation

Table 2. ***In vitro*** **mycelial growth inhibition of** ***Magnaporthe oryzea*** **by different bacterial isolates at various days after incubation (DAI)**

Treatments	Mycelial growth (cm) with days						% Growth inhibition over control at 15 DAI
	2 days	4 days	6 days	8 days	10 days	15 days	
Control	0.73 a	1.00 a	1.40	2.03	4.83 a	6.23 a	-
Isolate 1	0.30 b	0.73 ab	1.43	1.87	2.27 b	3.20 b	48.6
Isolate 2	0.33 b	0.70 ab	1.23	1.37	1.40 b	1.43 c	77.0
Isolate 3	0.30 b	0.73 ab	1.37	1.87	2.17 b	3.10 b	50.2
Isolate 4	0.30 b	0.53 ab	1.33	1.73	1.97 b	2.97 b	52.3
Isolate 5	0.30 b	0.47 b	1.27	1.77	2.10 b	3.13 b	49.8
Isolate 6	0.27 b	0.57 ab	1.07	1.66	1.90 b	2.60 b	58.3
F-test (at 5%)	S	S	NS	NS	S	S	-
CV (%)	23.33	24.79	15.38	13.83	15.28	7.77	-

Figures in a column with different letters are significantly different. DAI- Days After Incubation

Field trial

Field-based assessment was performed to examine the effectiveness of six bacterial isolates (Isolate 1 to Isolate 6) in controlling blast disease in rice (Figure 2). The treatments included seed priming and seedling priming with each isolate, along with absolute control group. Disease assessment was conducted by measuring leaf blast disease incidence and severity (Table 3). There was no neck blast found. The control treatment had the highest disease incidence both per plot (91.67%) and per hill (91.44%), demonstrating the absence of any protective measure. Treatments involving seed priming and seedling priming generally reduced the incidence of blast compared to the control. T_2 (52.78%) and $T_{5,}T_8$ (61.11%) showed significantly lower incidence rates per plot, indicating a notable reduction compared to the control (Table 3). Infected tiller percentages varied, with T_1 showing the lowest infection at 55.34%, suggesting effective reduction in disease spread as per tiller basis. The severity of the disease, both per plot and per tiller or per hill, was highest in the control group, confirming the detrimental impact of the disease when there was no bacterial treatment applied. Almost all treatments substantially lowered the disease severity per plot and per tiller compared to the control one.

Table 3. Effect of different bacterial isolates as seed treatment and root colonization of seedlings on leaf blast disease of rice

Treatments	Leaf blast disease incidence		Leaf blast disease severity (%)	
	% incidence of blast/plot	% infected tiller/hill	Disease severity/plot	Disease severity/hill
Control	91.67 a	91.44 a	3.64 a	2.00 a
T_1	75.00 ab	55.34 b	1.84 b	1.29 ab
T_2	52.78 b	72.48 ab	2.01 b	1.00 b
T_3	63.89 b	88.43 a	1.99 b	1.56 ab
T_4	69.44 ab	87.20 a	2.20 b	1.33 ab
T_5	61.11 b	82.67 a	1.67 b	1.00 b
T_6	69.44 ab	85.67 a	2.02 b	1.00 b
T_7	77.78 ab	84.26 a	2.07 b	1.50 ab
T_8	61.11 b	87.90 a	2.20 b	1.50 ab
T_9	72.22 ab	88.99 a	1.94 b	1.17 ab
T_{10}	69.44 ab	82.67 a	1.67 b	1.17 ab
T_{11}	75.00 ab	89.21 a	2.38 b	1.17 ab
T_{12}	66.67 ab	89.44 a	2.31 b	1.00 b
F-test (at 5%)	S	S	S	S
CV (%)	13.09	7.70	15.44	21.87

T_1= Seed priming with Isolate 1, T_2= Seed priming with Isolate 2, T_3= Seed priming with Isolate 3, T_4= Seed priming with Isolate 4, T_5= Seed priming with Isolate 5, T_6= Seed priming with Isolate 6, T_7= Seedling priming with Isolate 1, T_8= Seedling priming with Isolate 2, T_9= Seedling priming with Isolate 3, T_{10}= Seedling priming with Isolate 4, T_{11}= Seedling priming with Isolate 5, T_{12}= Seedling priming with Isolate 6.

T_1 and T_5 were particularly effective, showing the lowest severity per plot (1.84 and 1.67, respectively) and per tiller (1.29 and 1.00, respectively), indicating their potential efficacy in managing disease symptoms (Table 3). Seed priming (T_1-T_6) and seedling priming (T_7-T_{12}) with different isolates did not show a consistent trend in disease severity reduction, suggesting that the efficacy may depend on specific interactions between the bacterial isolate and the test plant.

In addition to disease assessment, the effect of bacterial treatment on plant growth parameters and major yield attributes as panicle length and grain yield were evaluated (Table 4). The influence of bacterial isolates on plant height showed variation across treatments but was statistically non-significant at the 5% level. The control treatment had an average plant height of 96.73 cm. Among the treatments, T_1 (Seed priming with Isolate 1) had the highest plant height (100.73 cm), while T_7 (Seedling priming with Isolate 1) showed the lowest (94.47 cm). However, since the differences were not statistically significant, it suggests that the bacterial isolates did not have a consistent or notable impact on plant height. The total tiller number varied among the treatments but did not show statistically significant differences. The control treatment had 8.47 tillers. T_9 (Seedling priming with Isolate 3) resulted in the highest total tiller number (11.73), whereas the control had the lowest tiller count. This suggests variability in the response to bacterial treatment, though it was not significant enough to draw conclusive results. Similar to total tillers, effective tiller number did not show significant differences across treatments. The control had 5.73 effective tillers, while T_9 had the highest effective tiller count at 6.80. The treatments exhibited some variation but without statistical significance, indicating that while some treatments might have improved tillering, the results were inconsistent. Panicle length showed slight variations across treatments but was not statistically significant. The control had a panicle length of 28.67 cm. The most prolonged panicle length was observed in T_{12} (seedling priming with Isolate 6) at 29.20 cm, while the shortest was in T_{10} (Seedling priming with Isolate 4) at 27.87 cm (Table 4). The results suggest that bacterial treatment did not significantly affect panicle length. Yield was the only parameter significantly influenced by the bacterial isolates ($P < 0.05$). The control treatment had a yield of 128.72 g/m², the lowest among all treatments. T_5 (Seed priming with Isolate 5) achieved the highest yield at 358.20 g/m². Other high-yielding treatments included T_1 (331.57 g/m²), T_8 (342.98 g/m²), and T_7 (280.65 g/m²). The variation in yield suggests that some bacterial isolates significantly enhanced productivity compared to the control, indicating a beneficial effect of certain treatments on yield.

Numerous microorganisms, particularly fungi and bacteria, exhibit antagonistic activity against *Magnaporthe oryzae*, the causal agent of rice blast. Among biocontrol agents, members of the genera *Bacillus*, *Streptomyces*, *Pseudomonas*, *Chryseobacterium* and *Rhizobacteria* have demonstrated significant *in vitro* efficacy against the pathogen (Chakraborty *et al*., 2021). Singh and Brar (2020) reported that *Streptomyces albidoflavus* alone inhibited *Magnaporthe oryzae* mycelial growth by 55.3-24.3%, while a consortium of *Streptomyces albidoflavus*, *Bacillus subtilis* and *Bacillus cereus* achieved 89-90% suppression. Similarly, diverse *Streptomyces* strains including *S. palmae* PC12, *S. vinaceusdrappus* and *S. philanthi* RM-1-138 have shown variable rates (22-98%) in laboratory assays (Chakraborthy *et al*., 2021). The observed antifungal activity against

Magnaporthe oryzae can be attributed to the secretion of a diverse array of inhibitory compounds by antagonistic bacteria. As documented in the literature, such inhibition often results from the production of hydrolytic enzymes (Fujimoto and Kupper, 2016), peptide antibiotics (Mannanov and Sattarova, 2001), and volatile extracellular metabolites (Podile *et al*., 1987). Specific studies have highlighted the role of key lipopeptides; for instance, the inhibition by *Bacillus* species has been linked to the secretion of fengycin and bacillomycin (Cao *et al*., 2011), while compounds like mycosubtilin and zwittermicin have also been identified as critical antibacterial agents (Pal and Gardener, 2006). Despite the identification of these broad inhibitory mechanisms, the specific factors that drive strain-level variation in antifungal efficacy such as differences in compound expression, synergy, or environmental interaction remain poorly understood. Therefore, while the general inhibitory capacity is established, the precise mechanistic basis for the superior performance of specific strains or consortia, such as the combination treatment reported by Singh and Brar (2020), warrants further molecular and metabolomic investigation. Notably, *Streptomyces globisporus* JK-1 not only restricted mycelial growth in dual cultures but also impaired conidial germination and appressorial formation in detached leaf assays (Li *et al*., 2011), suggesting multifaceted modes of action.

Table 4. Impact of Different bacterial isolate as seed treatment and root colonization on plant height, tillering, panicle length, and yield in field trials

Treatments	Plant heights (cm)	Total tiller/hill (No.)	Effective tiller/hill (No.)	Panicle length (cm)	Yield (g/m^2)
Control	96.73	8.47	5.73	28.67	128.72 b
T_1	100.73	9.33	6.53	28.93	331.57 a
T_2	98.27	10.80	6.20	28.40	231.76 ab
T_3	99.73	11.13	6.60	28.93	208.93 ab
T_4	100.27	10.47	6.53	28.13	232.95 ab
T_5	98.00	9.40	5.93	28.07	358.20 a
T_6	95.33	9.87	5.73	28.47	201.65 ab
T_7	94.47	11.67	6.53	28.13	280.65 ab
T_8	96.33	10.87	6.73	28.60	342.98 a
T_9	98.47	11.73	6.80	28.53	198.74 ab
T_{10}	95.60	9.93	5.67	27.87	237.92 ab
T_{11}	97.20	11.00	5.87	29.07	206.77 ab
T_{12}	98.27	10.73	5.93	29.20	278.12 ab
F-test (at 5%)	NS	NS	NS	NS	S
CV (%)	2.45	26.55	16.70	2.42	25.03

T_1= Seed priming with Isolate 1, T_2= Seed priming with Isolate 2, T_3= Seed priming with Isolate 3, T_4= Seed priming with Isolate 4, T_5= Seed priming with Isolate 5, T_6= Seed priming with Isolate 6, T_7= Seedling priming with Isolate 1, T_8= Seedling priming with Isolate 2, T_9= Seedling priming with Isolate 3, T_{10}= Seedling priming with Isolate 4, T_{11}= Seedling priming with Isolate 5, T_{12}= Seedling priming with Isolate 6.

The results indicate that seed and seedling priming with selected bacterial isolates (Isolate 1 to Isolate 6) effectively reduced the incidence and severity of leaf blast disease in rice under field conditions. Treatments T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{11} and T_{12} consistently showed lower disease incidence and severity compared to the untreated control. These findings indicate that the tested bacterial isolates could serve as effective biocontrol agents against rice blast disease. Supporting this, Shimoi *et al*. (2010) reported that rice plants inoculated with *Acidovorax* sp., *Chryseobacterium* sp. and *Sphingomonas* sp exhibited significantly lower blast incidence and severity, with disease indices ranging from 0.66 to 1.13 compared to 2.54 in non-inoculated controls. Similarly, Zanardi *et al*. (2009) demonstrated in greenhouse trial that *Streptomyces sindeneusis* isolate 263 strongly inhibited *Magnaporthe oryzae*, suppressing rice blast development. Further evidence comes from Rais *et al*. (2018), where three *Bacillus* spp. Strains (KFP-17, KFP-7 and KFP-5) markedly reduced infection rates in aromatic rice varieties Basmati-385 and Super Basmati. Notably, seed treatment with *Bacillus amyloliquefaciens* UASBR9 resulted in a disease severity of just 0.96%, far below the 3.43% observed in untreated controls (Amruta *et al*., 2018). In rice cultivation, leaf blast is more severe in the Boro season compared to neck blast due to several agronomic and climatic factors. Leaf blast occurs at an earlier growth stage of the rice plant when leaves are tender and actively growing. In Boro season, these young leaves are more susceptible because the climatic conditions favor the disease. Neck blast generally affects the plant at the reproductive stage when the panicles (flowering heads) are exposed. By this time in the Boro season, environmental conditions may have changed, becoming less favorable for neck blast development compared to the earlier stages when leaf blast occurs.

Despite the reduction in disease, the bacterial treatments did not significantly improve growth parameters in rice such as plant height, total tiller number, effective tiller number, and panicle length, though yield did improve. The variability among treatments suggests further research is needed to optimize application methods and explore factors affecting efficacy. This study highlights the viability of these bacterial isolates as biocontrol agents against rice blast disease and underscores the need for ongoing research to maximize their benefits.

Conclusion

Among the six effective bacterial isolates screened from an initial thirty, Isolate 2 emerged as the most potent antagonist in vitro, demonstrating the highest mycelial growth inhibition of *Magnaporthe oryzae* at 77.0% over 15 days. The field trial validated the practical efficacy of these isolates, showing that both seed and seedling priming treatments significantly reduced leaf blast incidence and severity compared to the untreated control. The most effective disease control, as measured by the lowest disease severity per plot (1.67) and per tiller (1.00), was achieved by T_5 (Seed priming with Isolate 5) and T_2 (Seed priming with Isolate 2). Crucially, the application of specific bacterial isolates directly enhanced grain yield, with T_5 and T_8 (Seedling priming with Isolate 2) producing the highest yields of 358.20 g/m² and 342.98 g/m², respectively a significant increase over the control (128.72 g/m²). This study confirms that seed priming with Isolate 5 is a highly promising integrated management strategy, as it effectively suppresses rice blast while substantially boosting crop productivity.

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