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EVALUATING THE IMPACT OF BIOAGENTS, ANTIBIOTICS AND CHEMICALS ON RICE BACTERIAL LEAF BLIGHT

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ABSTRACT

Bacterial leaf blight (BLB), caused by *Xanthomonas oryzae* pv. *oryzae* (Xoo), is a major disease of rice causing substantial yield losses. This study evaluated the efficacy of antibiotics against Xoo under laboratory conditions and assessed promising bioagents, antibiotics, chemicals and nutrient formulations for BLB management under field conditions. *In vitro* evaluation of thirteen antibiotics (100–1000 ppm) revealed significant differences in antibacterial activity. Bacteriocin was the most effective, producing the largest inhibition zone (6.72 cm at 1000 ppm), followed by streptomycin sulphate (90%) + tetracycline hydrochloride (10%) (5.76 cm), whereas ampicillin showed no inhibition. Based on laboratory performance, selected treatments were evaluated during the Pishanam seasons (2020–2022) using susceptible rice varieties ADT 38 and ADT 45. Among the eleven treatments tested, foliar application of copper hydroxide (0.25%) + streptomycin sulphate (150 ppm), applied at disease onset and repeated after 15 days, consistently provided the best disease management. Pooled analysis recorded the lowest disease intensity (9.48%), the highest disease reduction (78.67%), maximum grain yield (5,979 kg ha^{-1}) and the highest benefit-cost ratio (2.21). Copper hydroxide (0.25%) + potassium nitrate (0.5%) was the next best treatment, showing comparable disease suppression and yield improvement. These findings demonstrate that copper hydroxide combined with streptomycin sulphate is an effective, economical and practical option for managing bacterial leaf blight in rice.

Key words : Antibiotics, Bacterial leaf blight, Biocontrol agents, Fungicides, *Xanthomonas oryzae* pv. *oryzae*, Rice.

Introduction

Rice (*Oryza sativa* L.) is one of the world's most important cereal crops and serves as the primary staple food for more than half of the global population. It is a major source of carbohydrates and also contributes proteins, vitamins, minerals and essential micronutrients to human nutrition. With the continuous growth of the global population, increasing rice productivity has become a major challenge for ensuring food and nutritional security. However, rice production is severely constrained by several biotic stresses, among which bacterial leaf blight (BLB) caused by *Xanthomonas oryzae* pv. *oryzae* (Xoo) is considered one of the most destructive diseases affecting rice cultivation throughout Asia and several other rice growing regions of the world (Mew *et al.*, 1993).

Bacterial leaf blight was first reported in Japan during 1884-1885 and the causal organism was subsequently identified as *Bacillus oryzae* in 1911 before being reclassified as *Xanthomonas oryzae* pv. *oryzae* (Srinivasan *et al.*, 1959; Mansfield *et al.*, 2012). In India, the disease was first recorded in Maharashtra in 1959 and has since become widespread in almost all major rice-growing states (Srinivasan *et al.*, 1959). The extensive cultivation of high yielding but susceptible rice varieties coupled with favourable environmental

conditions has contributed to frequent disease outbreaks and substantial economic losses (Srivastava, 1967). Yield losses ranging from 20 to 50% are common under moderate disease pressure, while severe epidemics may result in losses exceeding 80%, particularly when infection occurs during the maximum tillering to booting stages (Srivastava, 1967; Prasad *et al.*, 2018). Owing to its economic significance and widespread distribution, Xoo has been recognized among the ten most important bacterial plant pathogens worldwide (Mansfield *et al.*, 2012).

The pathogen is a vascular, Gram-negative bacterium that primarily enters rice plants through hydathodes and wounds present along leaf margins. Following penetration, the bacterium colonizes the xylem vessels, multiplies rapidly and obstructs water movement, leading to systemic infection. Typical disease symptoms begin as water soaked lesions near the leaf tips or margins, which gradually enlarge into yellowish to straw coloured streaks with wavy margins. Under favourable environmental conditions, lesions extend along the leaf blade, eventually causing complete leaf blighting. Infection during the seedling stage results in the characteristic "Kresek" symptom, which is manifested by rapid wilting and death of young plants. Disease severity is influenced by several factors, including varietal susceptibility, environmental conditions, cropping practices and the virulence of pathogen populations (Reissig *et al.*, 1986).

Several disease management strategies have been explored to minimize losses caused by bacterial leaf blight, including host plant resistance, cultural practices, biological control, induced resistance and chemical management. Although resistant cultivars provide an economical and environmentally safe means of disease control, the durability of resistance is often compromised by the emergence of new pathogenic races capable of overcoming host resistance genes. Consequently, resistant varieties frequently become ineffective within a short period after their widespread cultivation (Xu *et al.*, 2010). Moreover, the continuous evolution of Xoo populations poses a major challenge to sustainable disease management.

Biological control has emerged as a promising alternative to chemical bactericides. Several antagonistic microorganisms, particularly *Bacillus subtilis* and *Streptomyces* spp., have demonstrated the ability to suppress Xoo through the production of antimicrobial metabolites, competition for nutrients and induction of systemic resistance in rice plants. Nagendran *et al.* (2013) reported that endophytic *Bacillus subtilis* significantly reduced bacterial leaf blight incidence under field conditions while simultaneously promoting plant growth. Similarly, resistance-inducing compounds such as chitosan have been shown to activate plant defence mechanisms, thereby reducing disease development.

Chemical control continues to play a crucial role in integrated disease management, particularly under conditions favourable for disease outbreaks. Copper based bactericides and antibiotic formulations have long been recommended for managing bacterial diseases in rice. Streptomycin and streptocycline either alone or in combination with copper compounds have demonstrated considerable efficacy against Xoo under both laboratory and field conditions (Rahul Singh *et al.*, 2015; Prasad *et al.*, 2018). However, prolonged and indiscriminate use of these bactericides has resulted in the emergence of antibiotic resistant pathogen populations in several rice-growing regions (Xu *et al.*, 2010; Zhu *et al.*, 2013). Similarly, resistance to bismerthiazol and other bactericides has also been reported, reducing their field effectiveness and emphasizing the need to identify alternative or integrated management strategies (Shi *et al.*, 2015; Yu *et al.*, 2016).

Recent investigations have highlighted the potential of naturally derived antimicrobial compounds, bacteriocins and integrated chemical combinations for improving disease suppression while minimizing the development of resistance. Bacteriocins, which are ribosomally synthesized antimicrobial peptides produced by bacteria, exhibit strong antibacterial activity against several phytopathogenic bacteria through disruption of cell membrane integrity (Negash and Tsehai, 2020). Likewise, Niclosamide has been reported to inhibit biofilm formation and reduce the virulence of Xoo, thereby suppressing bacterial leaf blight development (Sahu *et al.*, 2018). Despite these promising developments, comparative information on the effectiveness of biological agents, antibiotics, elicitors, nutrient formulations and copper based bactericides under field conditions remains limited.

Therefore, the present investigation was undertaken to evaluate the efficacy of selected bioagents, antibiotics, nutrient formulations and chemical bactericides, applied individually or in combination, against bacterial leaf blight of rice under laboratory and field conditions. The study aimed to identify an effective, economically viable and practically applicable disease management strategy capable of reducing bacterial leaf blight severity while improving grain yield under the rice-growing conditions of Tamil Nadu.

Materials and Methods

Experimental location

The investigation was carried out during the *Pishanam* (Rabi) seasons of 2020- 2021 and 2021-2022 to evaluate the efficacy of selected bioagents, antibiotics, elicitors, nutrients and chemical bactericides against bacterial leaf blight (BLB) of rice. Laboratory studies and field experiments were conducted at the Rice Research Station (RRS), Ambasamudram and in farmers' fields at Ayansingampatti, Tirunelveli district, Tamil Nadu. The susceptible rice cultivars ADT 38 and ADT 45 were used for all field evaluations.

Isolation and identification of *Xanthomonas oryzae* pv. *oryzae*

Rice leaves exhibiting characteristic bacterial leaf blight symptoms were collected from naturally infected fields. Diseased leaf tissues containing both healthy and infected portions were cut into small segments (approximately 3-5 mm). The leaf pieces were surface sterilized with 1% sodium hypochlorite solution for 30s and rinsed three times with sterile distilled water to remove traces of the disinfectant. The sterilized tissues were blotted dry on sterile filter paper and aseptically transferred onto nutrient agar (NA) medium following the procedure described by Di *et al*. (1991). The inoculated plates were incubated at 28 ± 2°C for 48 h. Developing bacterial colonies were purified by repeated streaking on fresh nutrient agar medium until uniform colonies were obtained. Pure cultures were maintained on nutrient agar slants and stored at 4°C for subsequent laboratory and field studies. Identification of the pathogen was based on colony morphology and characteristic cultural features of *Xanthomonas oryzae* pv. *oryzae*.

In vitro evaluation of antibiotics against *Xanthomonas oryzae* pv. *oryzae*

The antibacterial activity of thirteen antibiotics was assessed against *X. oryzae* pv. *oryzae* using the poisoned food technique. The antibiotics evaluated were Ampicillin, Bacteriocin, Bactrinashak, Carbenicillin, Chloramphenicol, Kanamycin, Niclosamide, Plantomycin, Rifamycin, Streptomycin sulphate, Streptomycin sulphate (90%) + Tetracycline hydrochloride (10%), Tetracycline hydrochloride and 2-bromo-2-nitropropane-1,3-diol. Each antibiotic was tested at five concentrations, namely 100, 250, 500, 750 and 1000 ppm. The required quantity of each antibiotic was incorporated into sterilized molten nutrient agar medium immediately before pouring into sterile 90-mm Petri plates. Plates containing nutrient agar without antibiotics served as the untreated control. Fortyeight hour old cultures of *X. oryzae* pv. *oryzae* were streaked onto the antibiotic amended medium under aseptic conditions and incubated at 28 ± 2°C for 72 h. After incubation, the diameter of the inhibition zone produced by each antibiotic was measured. The percentage inhibition was calculated using the method described by Vincent (1947). The antibiotics showing superior antibacterial activity under laboratory conditions were selected for further evaluation under field conditions.

Percentage Inhibition (PI) = Diameter of the zone of inhibition / Diameter of the petriplate × 100

Field evaluation of disease management treatments

Field experiments were conducted using a randomized block design (RBD) comprising eleven treatments with three replications. The experiments were carried out at two locations, during two consecutive *Pishanam (Rabi)* seasons (2020-2021 and 2021-2022). The susceptible rice cultivars ADT 45 and ADT 38 were used in the respective trials. All recommended agronomic practices were followed uniformly across treatments.

Foliar applications were initiated immediately after the appearance of initial bacterial leaf blight symptoms. A second spray was imposed 15 days after the first application. The treatments evaluated are presented below.

Trt. no.	Treatment details	Dosage
1.	Spraying of *Bacillus subtilis* (Bbv57)	0.5 %
2.	Spraying of *Streptomyces reticuli*	0.5 %
3.	Spraying of Potassium nitrate	0.5 %
4.	Spraying of Chitosan	0.5 %
5.	Spraying of Bacteriocin	500 ppm
6.	Spraying of Curd	0.5 %
7.	Spraying of Copper sulphate	0.25 %
8.	Spraying of Copper hydroxide	0.25 %+
9.	Spraying of Copper hydroxide + Potassium nitrate	0.25%+0.5%
10.	Spraying of Copper hydroxide + Streptomycin sulphate	0.25% + 150 ppm
11.	Untreated control	-

Disease assessment

Disease severity was recorded 15 days after the second spray by selecting twenty five leaves at random from each replication. Disease intensity was assessed according to the Standard Evaluation System (SES) for Rice developed by the International Rice Research Institute (IRRI, 2013). Disease severity ratings were

assigned using the standard 0–9 scale based on the percentage of leaf area affected. The Percent Disease Index (PDI) was calculated using the formula proposed by McKinney (1923)

$$\text{Percent Disease Index (PDI)} = \frac{\text{Sum of individual ratings}}{\text{Total number of leaves observed}} \times \frac{100}{\text{Maximum grade}}$$

Statistical analysis

The experiments were analyzed using the Randomized Block Design with three replications. Mean values were subjected to analysis of variance (ANOVA) using IRRISTAT Version 92 developed by the International Rice Research Institute (IRRI), Philippines. Treatment means were compared using the Least Significant Difference (LSD) test at the 5% probability level following the procedure described by Gomez and Gomez (1984). Differences among treatments were considered significant at $P \leq 0.05$.

Results and Discussion

Isolation and Identification of Xanthomonas oryzae* pv. *oryzae

Rice plants exhibiting typical symptoms of bacterial leaf blight (BLB) were collected from naturally infected fields for pathogen isolation. The disease symptoms initially appeared as paleyellow lesions near the leaf tips and margins, which gradually elongated into yellow to orange-brown streaks. As the infection progressed, the lesions coalesced, resulting in extensive straw-coloured blighting with irregular margins extending towards the leaf sheath. These characteristic symptoms are consistent with the typical manifestation of bacterial leaf blight caused by *Xanthomonas oryzae* pv. *oryzae* (Xoo).

Isolation of the pathogen on nutrient agar medium consistently yielded characteristic yellow, smooth, convex and mucoid bacterial colonies after 48 h of incubation at 27 ± 2°C. Repeated purification through streak plate technique resulted in uniform colonies that were maintained as pure cultures for subsequent laboratory and field investigations (Fig. 1). The colony morphology observed in the present investigation agreed well with the descriptions reported by Vinodhini and Kannan (2019), who described Xoo colonies as bright yellow, circular and mucoid on nutrient agar medium. Similar cultural characteristics have also been documented by Mew *et al.* (1993) and Mansfield *et al.* (2012), confirming the identity of the pathogen. The yellow pigmentation observed in Xoo colonies is attributed to the production of xanthomonadin pigments, which play an important role in protecting bacterial cells from photo oxidative damage and contribute to pathogen survival under field conditions.



Fig. 1 : Colony characters of *Xanthomanas oryzae* pv *oryzae*.

Accurate isolation and purification of the pathogen are essential prerequisites for evaluating antibacterial compounds because the use of a pure and virulent culture minimizes experimental variation and ensures reliable assessment of treatment efficacy. The present observations therefore confirmed the successful isolation of *X. oryzae* pv. *oryzae*, which served as the test pathogen for subsequent in vitro and field evaluations.

In vitro* evaluation of antibiotics against *Xanthomonas oryzae* pv. *oryzae

The efficacy of thirteen antibiotics against *X. oryzae* pv. *oryzae* was evaluated under laboratory conditions at five concentrations ranging from 100 to 1000 ppm. Significant differences were observed among the antibiotics with respect to their ability to inhibit bacterial growth, indicating considerable variation in antibacterial activity.

Among the tested antibiotics, Bacteriocin exhibited the highest antibacterial activity across all concentrations. The largest inhibition zone (6.72 cm) was recorded at 1000 ppm, demonstrating its superior efficacy against Xoo (Fig. 2). The next most effective treatment was the combination of Streptomycin sulphate (90%) +

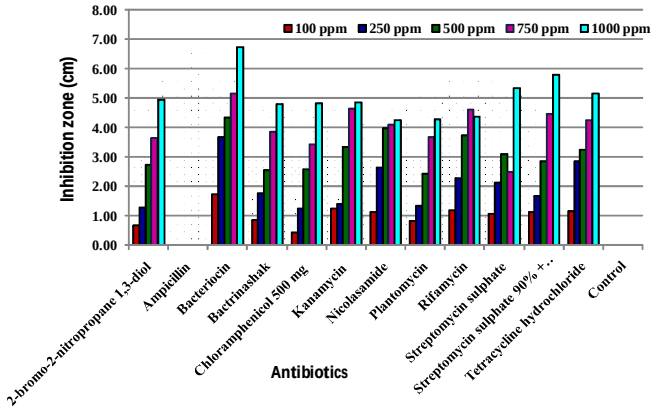


Fig. 2 : Inhibitory effect of antibiotics in *Xoo Xanthomanas oryzae pv oryzae* under *in vitro* condition.

Table 1 : Effect of different treatments on the intensity of bacterial leaf blight disease under *in vivo* condition (2020-21).

Trt. no.	Treatment details	Variety ADT 45			Variety ADT 38		
		BLB-PDI*	PROC	Yield (kg/ha)	BLB-PDI*	PROC	Yield (kg/ha)
1.	Spraying of *Bacillus subtilis* (Bbv57) @ 0.5 %	15.18^{bcd} (22.91)	34.92	5340^{bc}	28.52^{c} (32.27)	42.10	5123^{cd}
2.	Spraying of *Streptomyces reticuli* @ 0.5%	18.15^{d} (25.21)	22.22	5133^{cd}	35.18^{d} (36.38)	28.57	4950^{d}
3.	Spraying of Potassium nitrate @ 0.5%	13.33^{bc} (21.33)	42.86	5150^{cd}	29.26^{c} (32.74)	40.60	5133^{cd}
4.	Spraying of Chitosan @ 0.5%	14.81^{bcd} (22.59)	36.50	5183^{cd}	28.52^{c} (32.27)	42.11	5150^{cd}
5.	Spraying of Bacteriocin @ 300 ppm	13.70^{bc} (21.70)	41.27	5263^{cd}	28.15^{c} (32.01)	42.85	5083^{cd}
6.	Spraying of Curd @ 0.5%	15.18^{bcd} (22.89)	34.92	5133^{cd}	30.37^{c} (33.44)	38.35	5067^{cd}
7.	Spraying of Copper sulphate @ 0.25%	16.29^{cd} (23.76)	30.16	5237^{cd}	30.74^{cd} (33.65)	37.59	4987^{cd}
8.	Spraying of Copper hydroxide @ 0.25%+	12.22^{b} (20.45)	47.62	5817^{ab}	21.48^{b} (27.60)	56.39	5437^{bc}
9.	Spraying of Copper hydroxide @ 0.25% + Potassium nitrate @ 0.5 %	7.04^{a} (15.24)	69.84	5833^{a}	11.47^{a} (19.73)	76.70	5730^{ab}
10.	Spraying of Copper hydroxide @ 0.25% + Streptomycin sulphate @ 150 ppm	6.30^{a} (14.52)	73.02	6010^{a}	10.37^{a} (18.78)	78.95	6000^{a}
11.	Untreated control	23.33^{e} (28.87)	—	4853^{d}	49.25^{e} (44.57)		4777^{d}
	CD (0.05)	3.17		463.17	2.76		459.86
	CV%	8.54		5.07	5.18		5.17

BLB-Bacterial leaf blight disease; PROC- Per Cent Reduction Over Control; *Values are mean of three replications
For each treatment, numbers followed by the same letter are not significantly different according to LSD test at P <0.05

Tetracycline hydrochloride (10%), which produced an inhibition zone of 5.76 cm at the same concentration. In contrast, Niclosamide exhibited comparatively lower antibacterial activity, recording an inhibition zone of 4.23 cm, while Ampicillin failed to suppress bacterial growth even at the highest concentration tested. In general, the inhibitory effect increased progressively with increasing antibiotic concentration, indicating a clear dose dependent response. These findings suggest that bacteriocin and streptomycin based combinations possess greater bactericidal activity against Xoo than the other antibiotics evaluated. The superior performance of bacteriocin may be attributed to its unique mode of action. Bacteriocins are ribosomally synthesized antimicrobial peptides produced by bacteria that inhibit susceptible bacterial species by disrupting cell membrane integrity, altering membrane permeability and interfering with essential metabolic processes. Unlike conventional antibiotics, bacteriocins exhibit highly specific antibacterial activity while causing minimal adverse effects on beneficial microorganisms (Negash and Tsehai, 2020). Consequently, bacteriocins have gained considerable attention as environmentally safe alternatives for managing bacterial plant diseases.

The effectiveness of bacteriocin observed in the present study is consistent with the findings of Negash and Tsehai (2020), who reported that bacteriocins effectively suppress several phytopathogenic bacteria through membrane disruption and inhibition of cellular metabolism. Likewise, Xu *et al.* (2015) demonstrated that antimicrobial metabolites significantly reduced the growth and virulence of Xoo by affecting bacterial physiology and pathogenicity. These reports support the present observation that bacteriocin possesses strong antibacterial potential against the rice bacterial blight pathogen.

The combination of streptomycin sulphate and tetracycline hydrochloride also demonstrated excellent antibacterial activity. Streptomycin inhibits bacterial protein synthesis by binding to the 30S ribosomal subunit, whereas tetracycline interferes with aminoacyl-tRNA attachment during translation. The combined action of these antibiotics enhances bacterial growth suppression and delays the development of resistance. Similar results were reported by Patil *et al.* (2017), who observed that Streptocycline (streptomycin sulphate + tetracycline hydrochloride) significantly inhibited Xoo growth under laboratory conditions and effectively reduced bacterial leaf blight severity under field conditions. The poor performance of Ampicillin against Xoo observed in the present study suggests that the pathogen possesses either intrinsic or acquired resistance to β-lactam antibiotics. Similar observations were reported by Khan *et al.* (2012), who found that Ampicillin exhibited limited inhibitory activity against Xoo isolates compared with streptomycin and chloramphenicol. The increasing occurrence of antibiotic-resistant strains has become a major concern in rice disease management. Xu *et al.* (2010) further reported widespread streptomycin resistance among Xoo populations in China, emphasizing the necessity for identifying novel antibacterial compounds and adopting integrated disease management strategies to minimize the risk of resistance development.

Interestingly, although Niclosamide produced comparatively smaller inhibition zones than bacteriocin and streptomycin combinations, it nevertheless exhibited measurable antibacterial activity against Xoo. Sahu *et al*. (2018) demonstrated that Niclosamide effectively suppresses bacterial leaf blight by inhibiting biofilm formation, reducing bacterial motility and interfering with virulence associated genes rather than directly killing bacterial cells. Such differences in the mechanism of action may explain the relatively smaller inhibition zones observed under *in vitro* conditions while still providing effective disease suppression in planta.

In vivo management of BLB in rice

Field evaluation of eleven treatments over two consecutive Pishanam seasons (2020–21 and 2021-22) at two locations revealed significant differences in their ability to suppress bacterial leaf blight (BLB) and improve grain yield. Across all trials, foliar application of copper hydroxide (0.25%) combined with streptomycin sulphate (150 ppm) consistently recorded the lowest disease intensity, highest grain yield and superior economic returns, demonstrating its effectiveness under diverse field conditions.

During the 2020-21 season, copper hydroxide (0.25%) + streptomycin sulphate (150 ppm) reduced disease severity to 6.30% in ADT 45 under farmers' field conditions and 10.37% in ADT 38 at the Rice Research Station, recording disease reductions of 73.02% and 78.95%, respectively. The treatment also produced the highest grain yields of 6010 and 6000 kg ha^{-1} (Table 1). Similarly, during 2021-22, the same treatment recorded disease intensities of 8.52% and 8.89%, with corresponding grain yields of 6112 and 5637 kg ha^{-1} and benefit cost ratios of 2.12 and 2.16 under farmers' field and research station conditions, respectively (Table 2). Copper hydroxide (0.25%) combined with potassium nitrate (0.5%) was statistically comparable to the best treatment in disease suppression, grain yield and economic returns across seasons.

The pooled analysis further confirmed the superiority of copper hydroxide (0.25%) + streptomycin sulphate (150 ppm), which recorded the lowest pooled disease intensity (9.48%), highest disease reduction over control (78.67%), maximum grain yield (5979 kg ha^{-1}) and the highest benefit-cost ratio (2.21). Copper hydroxide + potassium nitrate ranked second with a disease intensity of 10.29%, grain yield of 5738 kg ha^{-1} and B ratio of 2.19, remaining statistically comparable with the superior treatment (Table 3). These results demonstrate the consistency and stability of the treatment across years and locations, suggesting its suitability for practical field application.

The enhanced efficacy of copper hydroxide combined with streptomycin sulphate can be attributed to their complementary modes of action. Copper hydroxide acts as a protective bactericide by reducing bacterial inoculum on the leaf surface, whereas streptomycin inhibits bacterial protein synthesis, thereby suppressing multiplication of *Xanthomonas oryzae* pv. *oryzae*. Their combined application provides both preventive and curative effects, resulting in effective disease suppression and improved crop productivity. Similar observations were reported by Prasad *et al.* (2018), who demonstrated that streptomycin combined with copper-based bactericides significantly reduced BLB severity and increased rice yield. Likewise, Patil *et al*. (2017) reported that streptocycline in combination with copper fungicides effectively managed bacterial leaf blight under field conditions. Similar findings have also been documented by Thimmegowda *et al.* (2012), who observed superior disease suppression with integrated application of antibiotics and copper compounds compared with individual treatments.

Table 2 : Effect of different treatments on the intensity of bacterial leaf blight disease under field condition (2021-22).

Trt. no.	Treatment details	Variety ADT 45			Variety ADT 38		
		BLB-PDI*	PROC	Yield (kg/ha)	BLB-PDI*	PROC	Yield (kg/ha)
1.	Spraying of *Bacillus subtilis* (Bbv57) @ 0.5 %	21.85^{c} (27.84)	42.72	5320^{c}	28.52^{d} (32.28)	39.37	4880de
2.	Spraying of *Streptomyces reticuli* @ 0.5%	27.77^{e} (31.80)	27.20	4963^{d}	36.29^{e} (37.04)	22.83	4443^{f}
3.	Spraying of Potassium nitrate @ 0.5%	23.70^{cd} (29.13)	37.86	5177^{cd}	34.81^{e} (36.15)	25.98	4667^{ef}
4.	Spraying of Chitosan @ 0.5%	24.07^{cd} (29.38)	36.89	5333^{c}	27.40^{cd} (31.56)	41.73	4913de
5.	Spraying of Bacteriocin @ 300 ppm	21.11^{c} (27.35)	44.66	5010^{cd}	24.07^{c} (29.37)	48.82	5067^{cd}
6.	Spraying of Curd @ 0.5%	21.11^{c} (27.33)	44.66	5120^{cd}	30.37^{d} (33.43)	35.43	4693^{ef}
7.	Spraying of Copper sulphate @ 0.25%	27.03^{de} (31.32)	29.15	4997^{cd}	35.55^{e} (36.60)	24.41	4753^{e}
8.	Spraying of Copper hydroxide @ 0.25%+	13.70^{b} (21.70)	64.08	5700^{bc}	15.92^{b} (23.45)	66.14	5213^{bc}
9.	Spraying of Copper hydroxide @ 0.25%+ Potassium nitrate @ 0.5%	9.26^{a} (17.67)	75.73	5913^{ab}	9.26^{a} (17.67)	80.31	5467^{ab}
10.	Spraying of Copper hydroxide @ 0.25% + Streptomycin sulphate @ 150 ppm	8.52^{a} (16.87)	77.68	6112^{a}	8.89^{a} (17.28)	81.10	5637^{a}
11.	Untreated control	38.14^{f} (38.14)		4600^{e}	47.03^{f} (43.30)	—	4147^{g}
	CD (0.05)	2.35		356.28	2.37		292.53
	CV%	5.08		4.08	4.53		3.53

BLB-Bacterial leaf blight disease; PROC- Per Cent Reduction Over Control; *Values are mean of three replications
For each treatment, numbers followed by the same letter are not significantly different according to LSD test at P <0.05

Copper hydroxide combined with potassium nitrate also exhibited excellent disease suppression, indicating that adequate potassium nutrition may enhance host resistance by strengthening cell walls, improving physiological activity and reducing susceptibility to pathogen invasion. Potassium has been reported to improve plant defence mechanisms and increase tolerance to several bacterial diseases, thereby complementing the protective action of copper-based bactericides. The statistically comparable performance of this treatment suggests that it can serve as an effective alternative, particularly in situations where repeated antibiotic use should be minimized.

The present findings are also in agreement with reports on bacterial diseases of other crops. Jagtap *et al.* (2012) demonstrated effective management of bacterial blight of cotton using copper oxychloride combined with streptocycline, while Meena *et al.* (2017) and Ashish *et al.* (2016) reported similar success in managing bacterial blight of pomegranate through integrated application of copper-based chemicals and antibiotics. These studies collectively indicate that combining copper compounds with antibacterial agents provides broader and more consistent suppression of bacterial pathogens than individual treatments. Overall, the present investigation establishes that foliar application of copper hydroxide (0.25%) combined with streptomycin sulphate (150 ppm) at the initial appearance of disease symptoms, followed by a second spray after 15 days, is the most effective strategy for managing bacterial leaf blight of rice. The treatment consistently reduced disease severity, increased grain yield and provided higher economic returns across seasons and locations, making it a reliable recommendation for integrated management of bacterial leaf blight in rice-growing ecosystems.

Table 3 : Effect of different treatments on the intensity of bacterial leaf blight disease under *in vivo* condition (Pooled data).

Trt. no.	Treatment details	BLB -PDI*	Per cent reduction over control	Yield (kg/ha)	BCR
1.	Spraying of *Bacillus subtilis* (Bbv57) @ 0.5 %	26.52^{cd} (30.74)	40.33	4985^{bc}	2.07
2.	Spraying of *Streptomyces reticuli* @ 0.5 %	30.74^{e} (33.50)	30.84	4813^{c}	1.93
3.	Spraying of Potassium nitrate @ 0.5 %	28.29^{cd} (31.78)	36.33	4746^{c}	1.80
4.	Spraying of Chitosan @ 0.5 %	26.66^{cd} (30.84)	40.00	4938^{bc}	1.78
5.	Spraying of Bacteriocin @ 300 ppm	24.15^{c} (29.20)	45.67	4941^{bc}	2.04
6.	Spraying of Curd @ 0.5 %	26.00^{cd} (30.44)	41.50	4797^{c}	1.87
7.	Spraying of Copper sulphate @ 0.25 %	30.44d^{e} (33.23)	31.50	4746^{cd}	1.88
8.	Spraying of Copper hydroxide @ 0.25 %+	18.74^{b} (25.35)	57.83	5196^{b}	2.04
9.	Spraying of Copper hydroxide @ 0.25 %+ Potassium nitrate @ 0.5%	10.29^{a} (18.59)	76.84	5738^{a}	2.19
10.	Spraying of Copper hydroxide @ 0.25% + Streptomycin sulphate @ 150 ppm	9.48^{a} (17.81)	78.67	5979^{a}	2.21
11.	Untreated control	44.44^{f} (41.66)	—	4399^{d}	1.67
	CD (0.05)	2.91		376.81	
	CV %	7.74		5.87	

BLB-Bacterial leaf blight disease; *Values are pooled data of five field trials
For each treatment, numbers followed by the same letter are not significantly different according to LSD test at P < 0.05

Conclusion

The study revealed that bacteriocin was the most effective antibiotic against *Xanthomonas oryzae* pv. *oryzae*, followed by streptomycin sulphate + tetracycline hydrochloride under laboratory conditions. Field trials (*Pishanam*, 2020–2022) showed that foliar application of copper hydroxide (0.25%) + streptomycin sulphate (150 ppm) effectively reduced bacterial leaf blight severity and improved grain yield and economic returns. Copper hydroxide + potassium nitrate also provided comparable disease control. These findings support the integration of copper-based bactericides with effective antibacterial compounds for sustainable bacterial leaf blight management, while further multi-location validation is required before large-scale recommendation.

Declaration : The authors confirm that they do not have any conflicts of interest.

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