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Integrated management of banded leaf and sheath blight incited by *Rhizoctonia solani* in barnyard millet

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ABSTRACT

Barnyard millet (*Echinochloa* species) is one of the promising small millet crops commonly cultivated in marginal lands. This crop is seriously succumbed by the attack of banded leaf and sheath blight (BLSB) associated with *Rhizoctonia solani*. Hence, the present investigation was focused on integrated management by screening the resistant varieties and *in vitro* and *in vivo* evaluation of fungicides, bioagents and biorationals against *R. solani*. In candidate screening, out of 34 genotypes, four were found to be potential resistant donors in future resistance breeding whereas T4 (seed treatment and foliar spray of tebuconazole + trifloxystrobin @ 0.05%) proved to be the best control strategy under both *in vitro* and *in vivo* (*Kharif* and *Rabi*) conditions with highest disease inhibition, lowest AUDPC leading to maximum grain and fodder yield. While, T5 (combination of bioagents) noticed as the treatment with moderate control and better benefit- cost ratio. It is emphasized that a combination of tebuconazole + trifloxystrobin at 0.05% and bioagent consortia can be utilized with different modes of treatments and simultaneously exploiting the resistant donors for improved control of banded leaf and sheath blight. The findings of present investigation will be of prime use for devising more effective management strategies under varied environments in barnyard millet, thereby contributing to food security and high returns for the farmers.

Key words: *Rhizoctonia solani*, integrated disease management, screening, barnyard millet, banded leaf and sheath blight

Millets, otherwise known as nutri-cereals are one of the oldest cultivated crops known to humans (Choudhary *et al.,* 2023; Nagaraja *et al.,* 2023) and consist of two main groups *viz.,* major millets (sorghum and pearl millet) and minor/small millets based on grain size and area of cultivation (Goron and Raizada, 2015). The commonly cultivating small millets are finger millet (*Eleusine coracana)*, little millet (*Panicum sumatranse*), kodo millet (*Panicum scrobiculatum*), foxtail millet (*Setaria italica*), barnyard millet (*Echinochloa frumentacea*), proso millet (*Panicum miliaceum*) and brown top millet (*Brachiaria ramosa* L.) (Muthamilarasan and Prasad, 2021). Small millets are often referred as "orphaned cereal crops and climate smart crops" owing to their nutraceutical attributes and resilience to major biotic and abiotic stresses (Bandyopadhyay and Muthamilarasan*,* 2017). Despite being neglected in terms of intensive cultivation, small millets are staple food for millions of people across the world and continuously cultivated in marginal lands with minimal care (Anuradha *et al.,* 2021). Globally, India is the largest grower of millets with 26.6 per cent of the world and 83 % of Asia's millet cropping area (FAOSTAT, 2018).

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Among the small millets, barnyard millet (*Echinochloa* species) is India's second most and world's fourth most produced minor millet showing a firm upsurge in world production and contributing to food security (Renganathan *et al.,* 2020). It consists of two major species, *Echinochloa esculenta* (Japanese barnyard millet) and *Echinochloa frumentacea* (Indian barnyard millet) that are widely grown in India, China, Japan, Pakistan, Africa and Nepal (Paschapur *et al.,* 2021) and offers food security to many people in Asian and African countries, exceptionally in high altitude and tribal regions (Clayton and Renvoize, 1986; Renganathan *et al.,* 2020). It is locally known by various vernacular names like Shyama, Sanwa, Oodalu, Khira and Kutdrivalli all over India (ICRISAT, 2022).Globally, India is the leading producer of millets with an area of 0.458 M ha, production of 0.371 million tonnes and a productivity of 809 kg/ha (INDIASTAT, 2019-20). Barnyard millet is resilient to diverse extreme environments and is shown to be one of the best remunerative crops to small and marginal farmers (Bhatt *et al.,* 2023). In India, it is mainly restricted to two agro-ecological zones *viz*., the Himalayan region of Uttarakhand and the Deccan plateau region of Tamil Nadu (Patro *et al.,* 2018). Nevertheless, it is prone to several biotic stresses of which fungal diseases like grain smut (*Ustilago panici-frumentacei*), leaf blast (*Pyricularia grisea*) and banded leaf and sheath blight (BLSB) (*Rhizoctonia solani*) are the major concerns in successful cultivation of barnyard millet resulting in significant yield losses (Kumar, 2012; Kumar and Srivastava, 2020). In India, earliest report of BLSB caused by *R.solani* in barnyard millet was recorded in 2007 in Uttarakhand (Nagaraja *et al.,* 2007) and followed by (Kumar and Dinesh, 2009) from Madhya Pradesh. Per cent yield losses due to BLSB disease in barnyard millet were estimated to be ranged from 52.70 % to 67.20 % under natural conditions (Palanna *et al.,* 2021) making BLSB one of the most destructive diseases of barnyard millet.

Several attempts have been made by scientists globally (Singh *et al.,* 2018) and in India (Pralhad *et al.,* 2019) to control BLSB by developing resistant varieties, recommending the fungicide formulations and biocontrol agents under independent and integrated conditions. Integrated disease management is the practice of using a range of measures to prevent and manage diseases in crops (Mukhtar *et al.,*2023). However, monitoring of the emergence of new virulent strains is of great concern in resistant breeding with the stipulated cultivars available (Hunjan *et al.,*2022). Also, knowledge on effective novel fungicide molecules and biocontrol agents will enable the management of disease in integrated manner combining with resistant varieties and aiding in sustainable and cost-effective management of the disease (Carver *et al.,*2022). Hence, the present investigation was devised for evaluation and identification of candidate germplasm, novel fungicide molecules biorational and biocontrol agents under both laboratory and field conditions to scale down the disease. Implementation of disease resistant varieties integrated with chemical and biocontrol management provides an improved protection to crop under varied environmental conditions.

MATERIALS AND METHODS

Pathogen isolation and inoculum preparation

Infected barnyard millet leaves showing characteristic blight symptoms with profuse mycelial growth under moist conditions were collected from *Rhizoctonia solani* infected fields. The pathogen was initially isolated on PDA and further purified by hyphal tip method and single sclerotial method (Moni *et al.,* 2016; Thesiya *et al.,* 2023) thereafter incubated at 28±2°C for 5 days. For mass multiplication, 5 mm agar blocks as well as well grown sclerotial bodies were transferred to maize-sand meal agar medium and incubated for 10-12 days at 28±2°C (Hunjan *et al.,*2022). Inoculations were made by placing mycelial plugs or 2-4 sclerotial bodies beneath the leaf sheath along with moist cotton to facilitate early infection provided with sufficient moisture (Nadarajah *et al.,*2014).

Field evaluation of barnyard millet genotypes

A diverse panel of thirty-four (34) barnyard millet genotypes along with a resistant (PRB 903) and a susceptible check (LDR1) were screened under natural disease conditions to identify the potential resistant donors for resistant breeding programme. The experiment was carried during *Kharif* 2021 at Agricultural Research Station (ARS), Vizianagaram, Andhra Pradesh, India (18.1067° N, 83.3956° E) using randomized block design (RBD) maintained with triplicates. A plot size of 3 m × 1 m size was maintained in which two rows of tester lines were sandwiched on either side with susceptible line. The resistant and susceptible checks were planted for every five genotypes to be screened.

Standard agronomic practices were followed and a fertilizer schedule of 50: 40: 25 kg/ha of N:P:K was applied. Periodical observations were made for initiation and expression of blight symptoms on both leaves and sheath. The genotypes were evaluated by adopting disease score based on standard evaluation scale (SES), 0-9 scale (IRRI, 2014).

Evaluation of *in vitro* efficacy of fungicides and biocontrol agents (BCA)

Efficacy of integrated disease management components such as fungicide molecules, biocontrol agents and biorational was initially tested under laboratory conditions to evaluate their potential efficacy against test pathogen, *R. solani*. Different techniques such as poisoned food technique and dual culture technique were employed to evaluate the fungicide, biorationals and biocontrol agents, respectively.

Evaluation of fungicides by poisoned food technique: New fungicide molecules such as tebuconazole + trifloxystrobin 75WG were evaluated at 0.05%, 0.025%, 0.0125% concentration while, propiconazole 25 EC was screened at 0.10%, 0.50%, 0.025% concentration against *R. solani* using poisoned food technique. Poisoned media was prepared by thorough mixing the required quantity of double strength fungicide to 50 ml of sterilized distilled water (SDW) followed by transferring into 50 ml of sterilized cool molten double strength PDA medium, mixed thoroughly and poured into Petri plates. Five mm actively growing fungal disc from 4 days old culture was inoculated at the centre and then incubated at 28±1°C. All the treatments were made in four replicates. PDA medium without fungicide mixture was considered as check. The efficacy of each treatment was determined by measuring the radial growth of *R. solani*, using which per cent inhibition of pathogen growth over control was calculated by adopting the following formula given by Vincent (1947):

$$I = \frac{C - T}{C} \times 100$$

Where, I = Per cent inhibition in growth of test pathogen, C = Radial growth (mm) in control and T = Radial growth (mm) in treatment

Evaluation of biocontrol agents (BCA) by dual-culture technique: A phenotype-based screening, so called "dual culture assay" was carried to study the direct antagonistic activity of the BCA on the test pathogen (Raymaekers *et al.,* 2020). The antagonists evaluated against *R. solani* were namely *Trichoderma asperellum*, *Pseudomonas fluorescens*, *Bacillus subtilis* which were collected from Department of Biological Control, Vizianagaram, ANGRAU, Andhra Pradesh. A sterile Petri plate consisting of solidified PDA agar was simultaneously inoculated with 6 mm mycelial discs of three-day old fungal antagonist or streaking of bacterial bioagent and *R. solani* at equidistance. Petri plates inoculated solely with *R. solani* at one end was treated as control. All the treatments were made in triplicates. Inoculated plates were incubated at 28 ± 2°C for 4-5 days and periodically observed for the growth of pathogen covering full plate under control treatment (Kashyap *et al.,*2023; Sonavane and Sriram, 2020).

The efficacy of BCA was determined by calculating per cent inhibition of mycelial growth of test pathogen (Vincent, 1947) which was derived by measuring the radial growth of *R. solani*, zone of inhibition.

Integrated management of BLSB with novel fungicide molecules, bioagents and biorational under sick plot conditions

Following the *in vitro* efficacy evaluation of fungicides and bioagents against *R. solani* causing BLSB in barnyard millet, these components were tested under sick plot conditions (cv. LDR - 1) in different treatment combinations along with biorationals such as neem cake and panchagavya. The experiment was repeated in two environments *i.e., Kharif* 2021 and *Rabi* 2021-22 at ARS, Vizianagaram, Andhra Pradesh, India using RBD with triplicates for improved accuracy in recommending under natural farming conditions.

The treatment details were described in Table 1, in which the seed treatment (with the respective chemicals, bioagents and a biorational) was done prior to sowing. First spray of *Bacillus subtilis* @10 g/l, tebuconazole + trifloxystrobin @ 0.05 per cent propiconazole @ 0.1 per cent was done after the first appearance of BLSB *i.e.,* 30 DAS whereas, second spray of propiconazole @ 0. 1 % was done at 37 DAS. Disease severity of banded leaf and sheath blight was assessed based on standard evaluation scale (IRRI, 1996) at 37 DAS and 51 DAS.

Simultaneously, PDI and area under disease progress curve (AUDPC) was calculated to determine the effect of different treatments in controlling BLSB in barnyard millet. AUDPC was calculated by following the formula given by Wilcoxson *et al.* (1975).

$$AUDPC = \sum_{i=1}^{k} \frac{1}{2}\left(S_i + S_{i-1}\right) \times d$$

Where, S_i= Disease incidence at ith day of evaluation, k =Number of successive evaluations of the disease and d = Interval between i and i-1 evaluation of disease

Standard evaluation scale (SES) for sheath blight disease (IRRI, 2014)

0-9 scale	Disease severity	Reaction
0	No infection	Highly Resistant (HR)
1	Vertical spread of the lesion up to 20% of plant height	Resistant (R)
3	Vertical spread of the lesion up to 21-30% of plant height	Moderately Resistant (MR)
5	Vertical spread of the lesion up to 31- 45% of plant height	Moderately Susceptible (MS)
7	Vertical spread of the lesion up to 46-65% of plant height	Susceptible (S)
9	Vertical spread of the lesion up to 66-100% of plant height	Highly Susceptible (HS)

Per cent disease index (PDI) or Disease index (DI %) was calculated as:
PDI = [Sum (number of plants in disease category) × numerical value of disease category) × 100] / [(no. plants in all categories) × (maximum value on rating scale)] (Drizou *et al.,*2017)
Yield per plot was estimated for each genotype in grams/plot.

Table 1. List of treatments tested under sick plot conditions for their efficacy against BLSB disease in barnyard millet

Treatment	Application
T1	Seed treatment with *Trichoderma asperellum* @ 10 g/kg + soil application of *Trichoderma asperellu*m@ 2 kg talc formulation mixed with 8 kg Neem cake in 90 kg FYM incubated for 15 days.
T2	Seed treatment with *Pseudomonas fluorescens* @ 10 g/kg + soil application of *Pseudomonas fluorescen*s@ 2 kg talc formulation mixed with 8 kg Neem cake in 90 kg FYM incubated for 15 days.
T3	Seed treatment with *Bacillus subtilis* @ 10 g/kg + soil application of *Bacillus subtilis*@ 2 kg talc formulation mixed with 8 kg Neem cake in 90 kg FYM incubated for 15 days.
T4	Seed treatment with tebuconazole + trifloxystrobin 0.05% + foliar spray of tebuconazole + trifloxystrobin @ 0.05%.
T5	Seed treatment with *Pseudomonas fluorescens* @ 10 g/kg seed + soil application of *Trichoderma asperellum* @ 2 kg talc formulation mixed with 8 kg Neem cake in 90 kg FYM incubated for 15 days + foliar spray of *Bacillus subtil*is@ 10 g/l.
T6	Seed treatment with 3% solution of panchagavya.
T7 (Standard check)	Seed treatment with propiconazole 0.1% + 2 foliar sprays of propiconazole @ 0.1% at 15 days interval.
T8	Control

Observations on yield attributing parameters like 100 seed weight (g), seed yield per plot (kg/ha) were recorded at harvesting stage. Similarly, grain yield and fodder yield were measured after harvesting and benefit- cost ratio (BC ratio) was calculated for each treatment and accordingly compared with untreated check.

The experimental data obtained during lab and field experiments were analysed statistically by following complete randomized design (CRD) and RBD, respectively using SPSS software. The statistical inference was drawn at $p<0.01$ and $p<0.05$ for *in vitro* and *in vivo* conditions, respectively.

RESULTS AND DISCUSSION

Identification of resistant donors through barnyard millet candidate screening

Deployment of resistant varieties is one of crucial component of integrated disease management and thus identification of the resistant lines against BLSB is indispensable to scale down the disease in cost-effective and sustainable manner. The disease intensity ranged from 12.00% (VB-19-3) to 62.50% (VL-285) (Table 2). Based on the differential disease reaction of 34 genotypes determined by SES 0-9 scale, these genotypes were categorized into four (4) groups (Table 3). Checks recorded 84.80 % (susceptible check - LDR-1) and 12.00 % (resistant check - PBR 903) of PDI, respectively.

Among the four groups of disease reaction, four (4) genotypes (VBBC-340, VB-19-3, VB-19-4 and BHBMG-73) were shown resistant (R) reaction and six (6) genotypes (LRB-15, LRB-17, LRB-13, LRB-10, VL-283 and VL-285) shown susceptible reaction.

Rhizoctonia solani having necrotrophic pathogenic behavior reported to attack wide spectrum

Table 2. Screening for banded leaf and sheath blight resistance in barnyard millet genotypes

S.No	Cultivar/ Variety	Percent disease index (PDI)	Host reaction
1	BMV-600	32.50 (34.76)[klmno]	MR
2	VMBC-333	30.80 (33.71)[mno]	MR
3	VBBC-340	15.70 (23.34)[s]	R
4	ACM 15-353	32.50 (34.76)[klmno]	MS
5	DHBM 47-3	33.20 (35.18)[jklmn]	MS
6	DHBM 93-3	38.50 (38.35)[gh]	MS
7	DHBM 4-63	29.30 (32.77)[opq]	MR
8	DHBM 47-5-6	43.10 (41.03)[ef]	MS
9	VL 280	38.20 (38.17)[ghi]	MS
10	IIMR BM-3-1920	35.10 (36.33)[hijkl]	MS
11	VL 284	29.50 (32.9)[nop]	MR
12	TNEF 323	36.50 (37.17)[ghij]	MS
13	TNEF 322	39.70 (39.06)[fg]	MS
14	VL 285	62.50 (52.24)[b]	S
15	VL 283	54.60 (47.64)[cd]	S
16	BXMNDL-7	27.20 (31.44)[pq]	MR
17	VL-207	36.80 (37.35)[ghij]	MS
18	BHBMG-73	16.70 (24.12)[s]	R
19	LRB-10	57.60 (49.37)[c]	S
20	LRB-13	50.90 (45.52)[d]	S
21	LRB-14	44.90 (42.07)[e]	MS
22	LRB-15	54.40 (47.52)[cd]	S
23	LRB-17	54.30 (47.47)[cd]	S
24	LRB-24	26.80 (31.18)[pq]	MR
25	LRB-29	26.00 (30.66)[qr]	MR
26	LRB-30	23.20 (28.79)[r]	MR
27	VB-19-3	12.00 (20.27)[t]	R
28	VB-19-4	12.20 (20.44)[t]	R
29	VB-19-5	23.00 (28.66)[r]	MR
30	VB-19-6	36.20 (36.99)[ghijk]	MS
31	VB-19-7	38.80 (38.53)[gh]	MS
32	VB-19-12	34.40 (35.91)[ijklm]	MS
33	VL 257	31.40 (34.08)[lmno]	MS
34	VB-19-15	36.60 (37.23)[ghij]	MS
35	PRB 903 (R)	12.00 (20.27)[t]	R
36	LDR1 (S)	84.80 (67.05)[a]	HS
	CD ($p \leq 0.05$)	4.36	
	SEm±	1.54	

Figures in the parentheses are angular transformed values; Values with same alphabets are statistically not significant at $p \leq 0.05$.

of host varieties including both monocots and dicots causing a variety of disease symptoms (Lisiecki *et al.,* 2022). Albeit of its occurrence in severe form in host species, the stable resistance reaction by host varieties is rarely reported under natural conditions (Akhter *et al.,* 2015). Findings of the study are in accordance with Jain and Gupta (2010) who reported the occurrence of BLSB disease on foxtail millet and barnyard millet from Madhya Pradesh, India where, cultivar RBM 9-4 was found to be free from BLSB and six genotypes namely TNAU 128, TNAU 130, RAU 8, VL 29, VL 220 and RBM 12 were identified as resistant to BLSB. Whereas, Patro *et al.* (2019) noticed that none of the variety was found to be resistant among fourteen barnyard millet genotypes screened. Chouhan (2014) reported that among 21 little genotypes screened, five (5) were resistant, six (6) were moderately resistant, eight (8) were moderately susceptible and two (2) were susceptible to banded leaf and sheath blight in little millet.

Antagonistic evaluation of fungicides and bioagents *in vitro*

Evaluation of diversified management practices helps in the identification of the best. Hence, prior to evaluation of different treatments under field conditions, fungicides like propiconazole, tebuconazole and trifloxystrobin, biocontrol agents like *T. asperellum, B. subtilis and P. fluorescens* and biorational like panchagavya were laboratory evaluated for their ability to scale down the disease. Among the fungicide treatments, *R. solani* growth was significantly inhibited at tebuconazole + trifloxystrobin @ 0.05% (83.44%) and propiconazole @ 0.1 % (73.75%) (Table 4a). Among the bioagents, *T. asperellum* (71.56%) was found to be the most effective followed by *B. subtilis* (58.59%) while, *P. fluorescens* (54.08%) was found to be lowest among the bioagents (Table 4b). The results revealed that the fungicides were effective in inhibiting the complete growth of the pathogen only at the recommended dose under *in vitro* conditions. Hence, the fungicide molecules were opted to be tested at the recommended dosage under field (sick plot) conditions.

The present results are corroborated with the earlier findings of Usendi *et al.* (2020) who reported that *T. asperellum* (71.38%) was relatively more effective in inhibiting *R. solani* than *P. fluorescens* (64.44%) and *B. subtilis* (61.38%). Also, among the chemicals tested, propiconazole 25EC @ 0.1% and tebuconazole + trifloxystrobin 75WG @ 0.1% showed absolute inhibition of *R. solani* under *in vitro* conditions. Studies on successful progression from laboratory conditions to natural conditions were reduced in an unprecedented manner over the years (Bhuiyan *et al.,*2023) due to their variable unstable reactions under field conditions with environmental effect, thereby, minimizing the chances of incorporation of such results in plant protection recommendations (Kashyap *et al.,*2023).

Integrated management of BLSB using fungicides, bioagents and biorational under sick plot conditions

Based on the results under *in vitro* conditions, an experiment was conducted under sick plot conditions in *Kharif* 2021 and *Rabi* 2021-22 to evaluate different treatment combinations in integrated manner. Different treatment combinations include seed treatment (ST), soil application (SA) and foliar spray (FS) of bioagents, fungicides and biorational components in variety of combinations mentioned in Table 1. Characteristic symptoms of BLSB were observed at 30 DAS. Hence, the observations were recorded at 37 and 51 DAS following chemical and bioagent

Table 3. Categorization of different barnyard millet genotypes based on disease reaction against *R. solani*

S.No	Disease reaction	Number of genotypes	Genotypes
1.	Resistant (R)	4	VBBC-340, VB-19-3, VB-19-4, BHBMG-73
2.	Moderately Resistant (MR)	9	BMV-600, VMBC-333, DHBM 4-63, VL 284, BXMNDL-7, LRB-24, LRB-29, LRB-30, VB -19-5
3.	Moderately Susceptible (MS)	15	ACM 15-353, DHBM 47-3, DHBM 93-3, DHBM 47-5-6, VL 280, IIMR BM-3-1920, TNEF 323, TNEF 322, VL-207, LRB-14, VB-19-6, VB-19-7, VB-19-12, VL 257, VB-19-15
4.	Susceptible (S)	6	LRB -10, LRB-13, LRB-15, LRB-17, VL 283, VL 285

Table 4a. Efficacy of fungicides at different concentrations against *R. solani* under *in vitro* conditions

S. No	Fungicide	Mean radial growth (mm) (Per cent inhibition over control) *			
		Recommended dose (100%)	50% of recommended dose	25% of recommended dose	Mean
1	Tebuconazole + Trifloxystrobin 75 WG	0.00 (100)	13.25 (83.44)	28.5 (64.38)	13.92 (82.61)
2	Propiconazole 25% EC	0.00 (100)	21 (73.75)	55.5 (30.63)	25.50 (68.13)
	Mean	0.00 (100)	17.12 (78.6)	42.02 (47.37)	
	Control		80		
		Fungicide (F)	Concentration (C)	F × C	
	SEm±	0.45	0.45	0.45	
	CD (p≤0.01)	0.78	0.95	0.13	
	CV (%)		4.59		

*Mean of four replications; Figures in the parentheses are the per cent inhibition over control values.

Table 4b. Efficacy of biocontrol agents against *R. solani* under *in vitro* conditions

S. No.	Biocontrol agent	Mean radial growth (mm) (Per cent inhibition over control) *
1.	*Trichoderma asperellum*	22.75 (71.56)
2.	*Pseudomonas fluorescens*	36.74 (54.08)
3.	*Bacillus subtilis*	33.13 (58.59)
	Mean	30.87 (61.41)
	Control	80.00
	SEm±	0.92
	CD (p≤ 0.01)	1.30
	CV (%)	4.28

*Mean of four replications; Figures in the parentheses are the per cent inhibition over control values.

application. However, PDI was comparatively low in *Rabi* season than in *Kharif*. Among all the treatments, T4 (ST+FS with tebuconazole and trifloxystrobin) recorded the least PDI and highest inhibition over control in *Kharif* (84.05%) and *Rabi* (85.92%) followed by T7 (ST with propiconazole 0.1% and 2 FS of propiconazole 0.1% at 14 days interval) in *Kharif* (82.33%) and *Rabi* (81.55%) at 51 DAS (Table 5). Among the ecofriendly treatment combinations, T5 (ST *P. fluorescens,* SA *T. asperellum* and FS *Bacillus subtilis*) was found to be moderately effective after fungicide treatmentswith a PDI of 28.88 and 24.44% in *Kharif* and *Rabi,* respectively followed by T6 (ST panchagavya 3%) in *Kharif* (30.36%) and *Rabi* (28.88%). In considering bacterial antagonists, seed treatment and soil application of *B. subtilis* (T3, 38.79% inhibition) was more effective compared to *P. fluorescens* (T2, 26.72% inhibition) during *Kharif*. Further, similar trendwas observed in *Rabi*. With this, T2 was summarized as the least effective among the treatments studied. However, the highest PDI was recorded in T8, control *i.e.,* 85.92 % and 76.29 % in *Kharif* and *Rabi* respectively. Further, it was observed that T2, T4 and T5 treatments showed less inhibition over control in *Kharif* than in *Rabi*.

These results were in accordance with the findings of Malik *et al.* (2018) who reported foliar spray of trifloxystrobin 25 WG and tebuconazole 50 WG @ 0.05% was at par with validamycin @ 0.1% with 49.15% inhibition in maize, which is more effective than 0.1% propiconazole 5EC tested. Patro *et al.* (2018) have documented that soil application of *T. asperellum*, *P. fluorescens* and *B. subtilis* was more effective than seed treatment and soil application of any single bio-agent. They also demonstrated that sole application of *P. fluorescens* (74.06%) and *B. subtilis* (71.92%) relatively less inhibited *R. solani* than in combination i.e. *P. fluorescens*+ *B. subtilis* (28.21%) PDI. Kumar *et al.* (2020) reported the antifungal activity of panchagavya against major soil borne pathogens recording absolute inhibition in *R.solani, S.rolfsii* and *S. sclerotiorum*, while 90% inhibition observed in *F.solani* f. sp. *pisi* and *F. oxysporum* f. sp. *pisi.* Karthika *et al.* (2017) reported panchagavya 5% resulted in absolute inhibition of mycelial growth of *R. solani.* In contrary to bacterial antagonist findings, Raju *et al*. (2021) reported that seed treatment and soil application of *B. subtilis* resulted in 78.46% reduction and was more effective than seed treatment and soil application of *T. asperellum,* foliar spray of hexaconazole 0.2% which resulted in 71.30% reduction.

Summarizing this integrated treatment combinations, it was observed that the *in vitro* experimental results were consistent with the results under field conditions where, 0.05% tebuconazole + trifloxystrobin 75 WG was more effective than 0.1% propiconazole 25EC, while among biocontrol agents, fungal antagonist(*T. asperellum*) was found to be more effective than bacterial antagonists (*P. fluorescens* and *B. subtilis*). Also, T4 treatment was more effective under field conditions while relatively better inhibition was observed in *Rabi* season than the *Kharif* season.

Impact of different treatment combinations on disease progression of BLSB

Spatial and temporal progression of disease is calculated by employing trapezoidal method of area under disease progress curve (AUDPC) for all the imposed treatments during *Kharif* and *Rabi* 2021-2022. Among the treatment combinations, ST and FS with tebuconazole + trifloxystrobin 0.05% (T4) recorded the lowest AUDPC of 171.08 in *Kharif* and 124.32 in *Rabi.* The highest AUDPC was recorded by T8 (control), followed by T2 (ST and SA with *P.*

Table 5. Integrated efficacy of bioagents, fungicides and biorational application against *R. solani* under sick plot conditions

S. No.	Treatment	*Kharif* 2021			*Rabi* 2021-22		
		Per cent disease index (PDI)		Per cent inhibition over control @ 51 DAS	Per cent disease index (PDI)		Per cent inhibition over control @ 51 DAS
		37 DAS	51 DAS		37 DAS	51 DAS	
1	T1 (ST + SA of *T. asperellum*)	19.99 (26.56) [d]	33.33 (35.26) [d]	61.20	18.88 (25.75) [d]	32.22 (34.58) [c]	57.76
2	T2 (ST + SA of *P. fluorescens*)	44.44 (41.81) [b]	62.96 (52.51) [b]	26.72	38.51 (38.36) [b]	50.36 (45.21) [b]	33.98
3	T3 (ST + SA of *B. subtilis*)	29.63 (32.98) [c]	52.59 (46.48) [c]	38.79	27.41 (31.57) [c]	48.14 (43.93) [b]	36.89
4	T4 (ST + FS of tebuconazole + trifloxystrobin 0.05%)	10.74 (19.13) [f]	13.70 (21.72) [e]	84.05	8.88 (17.34) [f]	10.74 (19.13) [f]	85.92
5	T5 (ST with *P. fluorescens* + SA of *T. asperellum* + FS of *B. subtilis*)	15.55 (23.22) [e]	28.88 (32.51) [d]	66.38	11.48 (19.81) [ef]	24.44 (29.63) [d]	67.96
6	T6 (ST with 3% panchagavya)	17.03 (24.37) [de]	30.36 (33.44) [d]	64.66	14.81 (22.63) [e]	28.88 (32.51) [c]	62.14
7	T7 (ST + 2 FS with propiconazole 0.1%)	11.11 (19.47) [f]	15.18 (22.93) [e]	82.33	10.74 (19.13) [f]	14.07 (22.03) [e]	81.55
8	T8 (Control)	56.29 (48.61) [a]	85.92 (67.96) [a]		48.14 (43.93) [a]	76.29 (60.86) [a]	57.76
CD (p≤ 0.05)		2.53	4.53		2.95	2.41	
SE(m)		0.83	1.48		0.97	0.79	
CV (%)		4.85	6.56		6.12	3.79	

ST: Seed treatment, SA: Soil application, FS: Foliar spray. Figures in the parentheses are angular transformed values. Values with same alphabets were statistically not significant at p≤0.05.

Table 6. Impact of various treatments on grain yield and fodder yield of barnyard millet under sick plot conditions.

S. No.	Treatment	*Kharif* 2021			*Rabi* 2021-22		
		Grain yield (kg/ha)	Fodder yield (kg/ ha)	B:C ratio	Grain yield (kg/ha)	Fodder yield (kg/ ha)	B:C ratio
1	T1 (ST + SA of *T. asperellum*)	1310.00	3033.67	1.54	1363.00	3168.67	1.60
2	T2 (ST + SA of *P. fluorescens*)	1256.00	2582.67	1.47	1229.67	2396.33	1.44
3	T3 (ST + SA of *B. subtilis*)	1236.67	2658.67	1.45	1280.33	2837.33	1.50
4	T4 (ST + FS with tebuconazole + trifloxystrobin0.05%)	1661.00	4245.67	1.82	1673.33	4338.30	1.83
5	T5 (ST with *P. fluorescens* + SA of *T. asperellum* + FS of *B. subtilis*)	1514.67	3709.00	1.75	1483.66	3832.00	1.72
6	T6 (ST with 3% panchagavya)	1350.67	3317.00	1.60	1396.67	3412.33	1.65
7	T7 (ST + 2 FS with propiconazole 0.1%)	1557.00	4086.00	1.80	1589.67	4144.67	1.84
8	T8 (Control)	1086.67	2340.33	1.29	1114.67	2803.67	1.34
CD (p≤ 0.05)		158.10	490.99		162.26	431.28	
SE(m)		51.62	160.32		52.98	141.48	
CV (%)		6.52	8.55		6.59	7.37	

ST: Seed treatment, SA: Soil application, FS: Foliar spray.

fluorescens) i.e., 751.80 and 539.14 in *Kharif* and *Rabi*. (Fig. 1). The AUDPC for all the treatments followed the similar trend in both *Kharif* and *Rabi*, while in *Kharif* 2021, AUDPC was relatively observed to be highest contrary to *Rabi* 2021-22.

Field assessment of grain and fodder yield impact in integrated treatment combinations

Grain and fodder being the most important parameter of varietal development, evaluation and improvement, it should be of prime concern for evaluation of integrated approaches. In this study, grain and fodder yield was relatively high for all treatments in *Rabi* season compared to *Kharif* (Table 6). This might be attributed to the high disease incidence in *Kharif* season compared *to Rabi* due to environmental conditions that favor the fast spread of *R. solani*. Among different treatments, T4 (ST and FS of 0.05% tebuconazole + trifloxystrobin) recorded highest grain yield of 1661 kg/ha and 1673.33 kg/ha in *Kharif* and *Rabi*, respectively. The fodder yield was also highest in T4 treatment in both *Kharif* and *Rabi* seasons. With high grain and fodder yield, T4 recorded highest benefit cost ratio of 1.82 in *Kharif* among all the treatments. T4 was followed by T7 (ST and 2 FS of 0.1%propiconazole 25EC) in grain

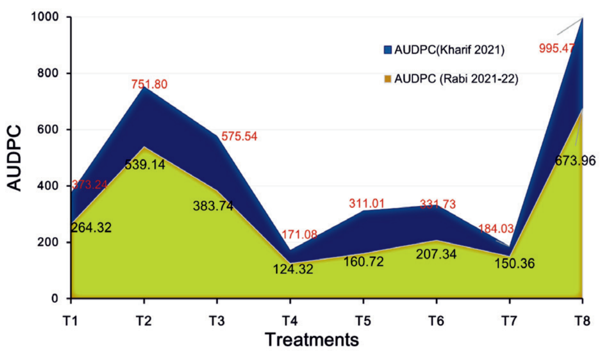

Fig. 1. **Impact of bioagents, fungicides and biorational application on disease progression of BLSB in barnyard millet**

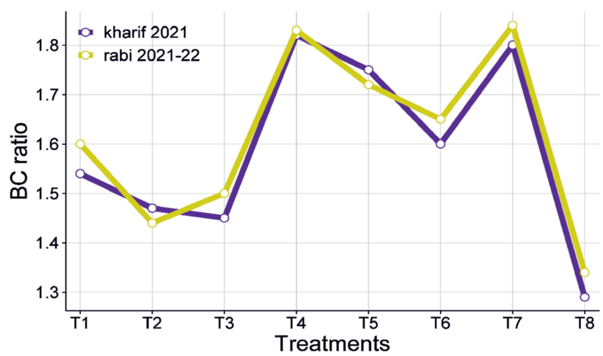

Fig. 2. **Impact of integrated treatment combinations on BC ratio of barnyard millet under sick plot conditions**

and fodder yield and recorded a benefit cost ratio of 1.80 in *Kharif*.

T5 was the most effective treatment even in terms of BC ratio (1.75) than treatment with any single bioagent (T1, T2, T3) (Fig. 2). Treatment with panchagavya @ 3% recorded high returns when compared to treatment with any single bioagent. However, it could not surpass T5, neither in yield nor in B:C ratio. As it can be observed that, the lower the PDI of the treatment, the higher were the yields and returns for that respective treatment. Further, it can be interpreted that, even the least effective among the seven treatments recorded a high B:C ratio over control, T8. Therefore, it can be emphasized that with better management practices leads to higher yields which in turn provide high returns.

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