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RESEARCH ARTICLE

Field assessment of cultivar mixtures for managing finger millet blast (*Pyricularia grisea*) using disease progress curves

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Abstract

The performance of cultivar mixtures under field conditions is pivotal for managing plant diseases, especially in mitigating air-borne pathogen epidemics in millets. This study evaluates the impact of various mixed-culture combinations on blast epidemics in finger millet, with a focus on ensuring yield stability. Disease progress curves for leaf, neck and finger blast were monitored at regular intervals. Repeated disease assessments were crucial for calculating the Area Under the Disease Progress Curve (AUDPC), a key indicator used to quantify the level of resistance to blast disease. Treatments included combinations of commercial variety and pre-released cultures paired with a resistant cultivar in different ratios (2:1 and 1:1) to curtail finger millet blast disease. Their effectiveness was equated with chemical/fungicide treatment. The pre-released cultures and resistant cultivar combination in a 1:1 share proved highly effective, significantly reducing the AUDPC values for leaf, neck and finger blasts whereas delivering sustainable outcomes. The cultivar mixture management practice performed comparably to chemical applications (Tricyclazole 75 % WP) during the 2020 and 2021 growing seasons. This cultural composite, delayed disease onset and slowed its progression during epidemics. The mixed-culture approach consistently achieved sustainable yields across trials while reducing the need for fungicidal applications.

Keywords: blast resistance; cultivar mixture; disease progressive curves

Introduction

Finger millet holds immense importance as a staple food, particularly among rural communities in East-Central Africa as well as Southern India. Originating in the Ethiopian highlands and the hills of Western Tanzania, this hardy crop is a key contributor in combating food insecurity and nutritional deficiencies, exclusively in densely populated regions like India. While wheat and rice are vital for mitigating these challenges, finger millet is notable for an important reservoir of vital minerals, 7-14 % of proteins, also contains amino acids free from gluten (1). Although *Eleusine coracana* L. Gaertn (finger millet) is among the hardiest of millet crops, it remains susceptible to different types of diseases, including mycotic infections such as blast, brown/*Helminthosporium* spot, sheath blight, green ear, foot rot and smut diseases (2). *Pyricularia grisea* (Cooke) Sacc. (Earlier *Pyricularia oryzae* Cavara.) caused the blast, the anamorph of *Magnaporthe grisea* (Hebert) Barr; is pathogenic to Poaceae family including 30 genera, with *Eleusine*, which comprises nearly 40 plant species (3). Infections by *M. grisea* can lead to severe reductions (up to 100 %) in biomass and mainly grain yield across various growth stages of finger millet, affecting the aerial parts viz., leaves, necks and the economical part, as fingers, in addition even discolouring the grains containing poor market value (4).

The characteristic leaf spots caused by this pathogen are spindle shaped, with a whitish or gray centre and reddish-brown to brown margins. In advanced stages, lesions may coalesce, resulting in complete leaf desiccation. The neck region and fingers are also susceptible, leading to reduced seed size and test weight (5, 6). The fungus's pervasive impact across all growth stages underscores the urgent need for effective management strategies against the blast pathogen to prevent yield losses in both grain and fodder (4) (Fig. 1). As the crop is primarily cultivated by resource-poor smallholder farmers under rain-fed conditions, the use of fungicides for disease management is often economically unfeasible. Moreover, the adaptability of *M. grisea* is generating novel pathogenic strains, which poses significant challenges to traditional resistance strategies (7). Epidemiologists have employed simple descriptive growth models for estimation rate parameters and

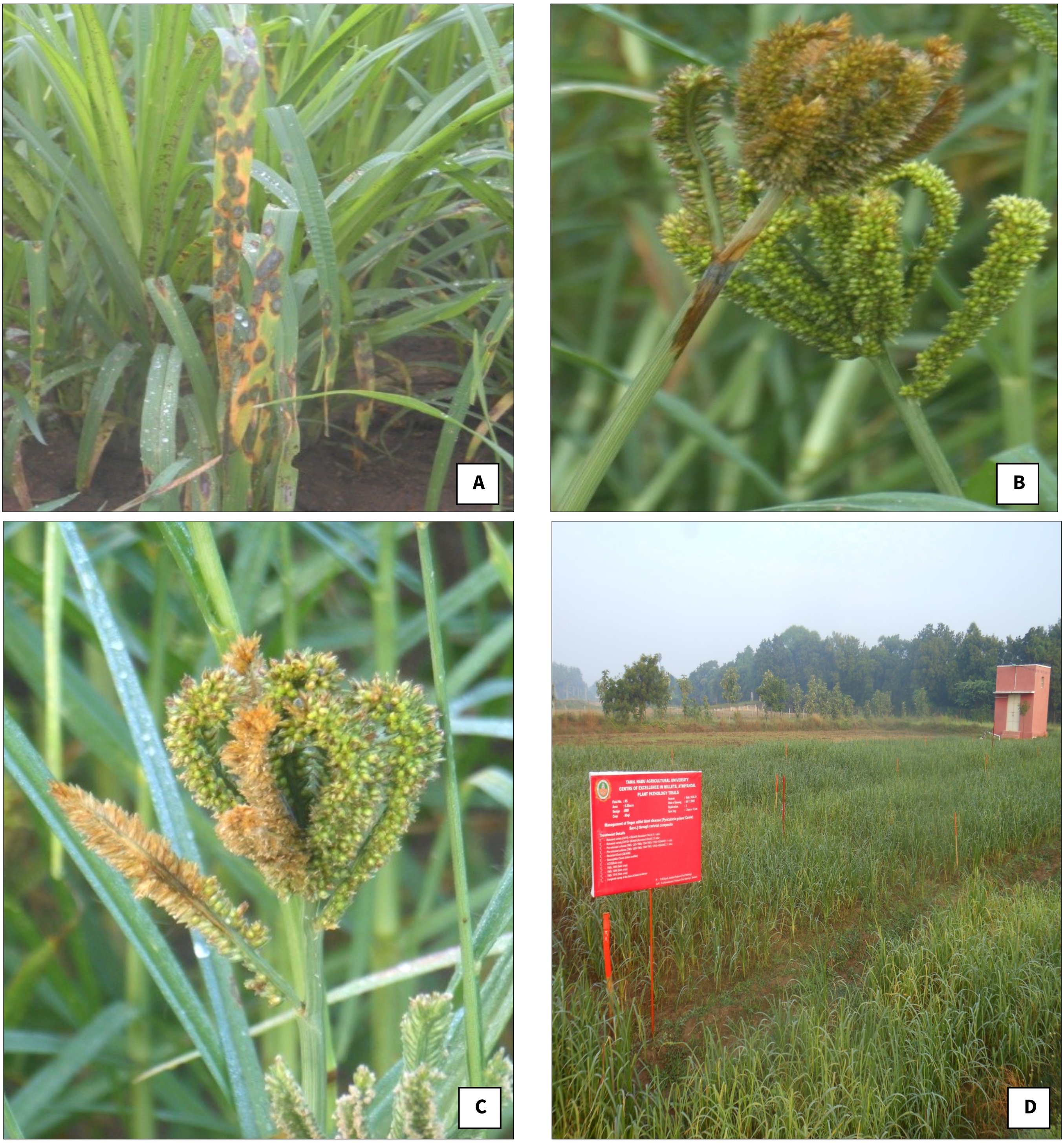

Fig. 1. Finger millet leaf, neck and finger/panicle blast symptoms on different plant organs with field view of trial: a. Typical leaf blast lesion, spindle-shaped with a gray or whitish centre and brown or reddish-brown margins; b. Blast symptom on the neck region, characterized by browning and blackening of the neck just below the fingers; c. The pathogen attacks the fingers, symptoms express from fingers to pedancle, causing them to become chaffy and producing shriveled, blackened seeds; d. The field view of varietal composite on blast disease epidemics of finger millet trial at Centre of Excellence in Millets, Athiyandal.

additional disease-progress metrics, which can be useful to differentiate cultivar types exhibiting distinct configurations of disease development under field conditions (8) otherwise in understanding how these patterns are influenced by various components of partial resistance (9). In finger millet, the incidence of neck and finger blast was lower across all treatments compared to the PRM 1 and VL 149 varieties. Notably, the mixture of VL 149 and PRM 1 in a 1:1 ratio achieved 94.14 % and 96.48 % neck blast control over VL 149 and PRM 1 respectively, while providing nearly, 70.00 % and 80.00 % finger blast control respectively (10). Recognizing the potential of variety mixtures to enhance functional diversity, limit pathogen epidemics and stabilize yields (11), this study focuses on two key objectives:

- To provide substantiation for the notion of functional diversity in pathogen management, as demonstrated by previous research in various crops.
- To evaluate different treatments, disease progress curves are used as a scale to assess the progression of epidemics.

Materials and Methods

Intervention design

Trials were conducted under natural disease pressure during the September 2020 and 2021 seasons under similar conditions. The experimental site was located at Athiyandal, Centre of Excellence in Millets (12°23'N, 70°02'E; elevation 280 m), Tamil Nadu Agricultural University (TNAU). A total of eleven treatments, including a chemical control, were evaluated. These treatments comprised both monocultures and varietal mixtures. The mixture treatments included the commercially popular variety CO 15, along with genotypes in the pre-release stage (TNEc 1310, TNEc 1294, TNEc 1285), combined in mixtures involving the resistant culture GE 4449 at 1:1 also 2:1 ratios. Released varieties, advanced breeding lines and resistant and susceptible monocultures were evaluated for their resistance to finger millet blast. The cultural composite treatments were compared with the recommended fungicide application for disease management. This involved tricyclazole 75 % WP two sprays at 500 g/ha, applied at the maximum tillering and flowering phases. The comparison also considered the financial implications of the treatments.

Treatment details

T_1: A mixture of CO 15 and the resistant line GE 4449 in a mixture of equal quantities

T_2: A mixture of CO 15 and GE 4449 in 2 parts to 1 part ratio

T_3: A mixture of pre-released cultures (TNEc 1285, TNEc 1294 and TNEc 1310) with GE4449 in a 1:1 ratio

T_4: A mixture of the same pre-released cultures with GE 4449 in a 2:1 ratio

T_5: GE 4449 sole crop, serving as the resistant check

T_6: Sole crop of *Udurumallige*, used as the susceptible check

T_7: Sole crop of the commercially popular variety CO 15

T_8: Sole crop of TNEc 1285 (pre-released culture)

T_9: Sole crop of TNEc 1294 (pre-released culture)

T_{10}: Sole crop of TNEc 1310 (pre-released culture)

T_{11}: Application of tricyclazole 75 % WP at 0.2 % concentration as two sprays - one at maximum tillering and the other at flowering stage, as the chemical control

A randomized block design was employed, with each treatment in triplicates. Finger millet was sown in September 2020 and 2021, with row and plant spacing maintained at 25 cm and 10 cm respectively, following standard agricultural practices prevalent in the region. No chemical treatments were imposed during the crop growth phase, except for two sprays of tricyclazole 75 % WP.

Disease scoring and PDI estimation

Disease incidence, specifically leaf blast, besides the percent disease index (PDI) was recorded by seven-day interims during the vegetative growth phase, from 14 to 42 day after sowing. Upon disease onset, chemical control was implemented using tricyclazole 75 % WP at 0.2 % concentration, applied once at 25 days after sowing (tillering stage) and again at 55–60 day after sowing (flowering stage). During the tillering stage, leaf blast incidence was recorded at weekly intervals from the 14^{th} to the 42^{nd} day after sowing, using a 1-9 scale, where 1 indicates resistance and 9 indicates susceptibility. Observations for neck and finger blast (panicle blast) were conducted as per the methodology mentioned by previous researchers (12). During the flowering phase, neck blast incidence was assessed weekly from the 70^{th} day to the 91^{st} day after sowing, while finger (panicle) blast incidence was recorded during the dough grain stage at 91, 98 and 105 days after sowing.

The standard evaluation system (SES) was used to assess leaf blast (13).

Leaf blast disease scoring scale (Standard Evaluation System):

Score 1: Tiny brown lesions of pinhead dimensions, with no evidence of sporulation at the centre.

Score 2: Necrotic grey lesions, 1-2 mm in diameter, ranging from round to slightly elongated, with well-defined brown margins. Lesions primarily confined to lower leaves.

Score 3: Similar in morphology to score 2 lesions, but notably more numerous on the upper leaves.

Score 4: Characteristic sporulating blast lesions measuring 3 mm or more in length, occupying less than 2 % of the total leaf area.

Score 5: Blast lesions of standard morphology affecting between 2 % and 10 % of the leaf area.

Score 6: Lesions characteristic of blast infection affecting 11 to 25 % of the foliar area.

Score 7: A moderate to severe incidence of blast lesions covering 26–50 % of the leaf area.

Score 8: Extensive blast infection observed on 51–75 % of the foliar area.

Score 9: Blast lesions affecting over 75 % of the total leaf surface.

The percentage of neck blast incidence was determined by dividing the number of infected panicles by the total number of panicles and multiplying by 100. To determine finger blast incidence (%), the number of infected panicles was multiplied by 100 and divided by the product of the average number of fingers per plant and the total number of panicles.

Disease progression curve

To compare disease intensities among different culture composites grown as pure stands (sole crops) and mixtures (1:1 and 2:1 ratios), along with the standard chemical treatment, cumulative disease intensity was measured using the AUDPC and scaled AUDPC values for the three types of blast. These calculations were performed independently using the methodologies outlined by previous researchers (14, 15).

Data analysis

The pooled experimental data from 2020 and 2021 were statistically analyzed using conventional standard procedures (16). Treatment effects were evaluated through analysis of variance (ANOVA), based on a randomized block design. Prior to analysis, percentage data for leaf, neck and finger blast incidence were subjected to arcsine transformation to meet the assumptions of ANOVA.

Results

Blast incidence

The disease progress curves (AUDPC) for the eleven treatments are presented in Table 1. The lowest AUDPC value (1570.75) was recorded in the chemical treatment (T_{11}). This was followed by TNEc 1285 + TNEc 1294 + TNEc 1310 (pre-released cultures) combined with GE 4449 (resistant culture) in a 1:1 ratio i.e., T_3, which recorded AUDPC pooled mean value of 1777.81 across the September 2020 and 2021 trials. The AUDPC values reflect the rate of disease progression, with culture composite treatments showing slower epidemic development in both seasons. In contrast, the chemical treatment demonstrated a sharp decline in the disease epidemic curve immediately after spraying (25 DAS). This treatment also recorded lower relative AUDPC values (0.561) and susceptibility rates (6.05) during September 2020 and 2021 trials.

The progression of neck and finger blast epidemics differed from that of leaf blast in both the September 2020 and 2021 trials. The treatment involving a 2:1 ratio of advanced breeding lines to the resistant culture (T_4) recorded a lesser AUDPC value of 1510.79 for neck blast incidence. For finger blast, the lowest incidence was observed in the T_3 treatment, with an AUDPC value of 210.00. Both T_3 and T_4 treatments showed comparable effectiveness in reducing the occurrence and severity of neck blast and finger blast incidence, ranking just below the fungicide spray treatment (Table 2).

Yield performance (Grain and fodder)

The mean results from the two trials indicated that the two-spray treatment with tricyclazole 75 % WP (T_{11}) resulted in a grain yield of 2304 kg/ha. This yield was statistically comparable to that obtained from the pre-released cultures mixed with the resistant culture in a 2:1 ratio (T_4), which produced 2291 kg/ha, as well as the 1:1 ratio mixture treatment (Table 3).

Table 1. Effect of varietal composite on leaf blast disease epidemics of finger millet (Pooled mean of September 2020 and 2021)

Tr. No.	Leaf blast PDI					AUDPC	rAUDPC	sAUDPC
	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS			
T_1	51.88 (46.06)	67.50 (55.22)	70.63 (57.16)	68.57 (55.88)	58.33 (49.78)	1832.60	0.655	7.06
T_2	53.13 (46.77)	69.58 (56.51)	76.56 (61.02)	73.21 (58.81)	61.25 (51.48)	1935.83	0.691	7.46
T_3	46.88 (43.19)	63.75 (52.96)	73.13 (58.75)	66.79 (54.79)	53.75 (47.13)	1777.81	0.635	6.85
T_4	48.13 (43.91)	64.58 (53.46)	73.75 (59.16)	67.50 (55.22)	55.00 (47.85)	1801.77	0.643	6.94
T_5	51.88 (46.06)	67.50 (55.48)	75.63 (60.39)	70.71 (57.21)	64.17 (53.21)	1905.94	0.681	7.34
T_6	72.08 (58.08)	82.19 (65.01)	88.89 (70.50)	86.56 (68.47)	80.00 (63.41)	2335.76	0.834	9.00
T_7	57.50 (49.29)	71.07 (57.44)	82.81 (65.48)	79.29 (62.90)	71.67 (57.82)	2084.27	0.744	8.03
T_8	59.50 (50.46)	72.86 (58.58)	85.31 (67.44)	83.57 (66.06)	77.50 (61.66)	2171.69	0.776	8.37
T_9	58.00 (49.58)	72.14 (57.89)	85.94 (67.95)	81.43 (64.45)	75.42 (60.25)	2141.02	0.765	8.25
T_{10}	59.50 (50.46)	73.21 (58.81)	86.25 (68.21)	81.07 (64.18)	77.50 (61.66)	2163.25	0.773	8.34
T_{11}	60.00 (50.75)	74.64 (59.74)	62.50 (52.22)	38.50 (38.34)	37.50 (37.75)	1570.75	0.561	6.05
S. Em	2.06	2.61	2.35	2.10	2.17			
CD at 5 %	4.17	5.38	4.89	4.28	4.62			

Figures in the parentheses are arcsine transformed values.

DAS - Day After Sowing, AUDPC - Area Under Disease Progress Curve, rAUDPC - Relative Area Under Disease Progress Curve, sAUDPC - Susceptible Area Under Disease Progress Curve

Table 2. Effect of varietal composite on neck and finger blast disease epidemics of finger millet (Pooled mean of September 2020 and 2021)

Tr. No.	Neck blast PDI				AUDPC	rAUDPC	sAUDPC	Finger blast PDI			AUDPC	rAUDPC	sAUDPC
	70 DAS	77 DAS	84 DAS	91 DAS				91 DAS	98 DAS	105 DAS			
T_1	11.67 (19.96)	16.67 (24.08)	20.00 (26.55)	23.33 (28.87)	2152.34	1.02	27.68	8.25 (16.69)	16.50 (23.96)	22.50 (28.31)	278.25	0.20	22.30
T_2	11.67 (19.96)	16.67 (24.08)	21.67 (27.73)	25.00 (29.99)	2205.16	1.05	28.24	8.75 (17.20)	17.00 (24.34)	23.00 (28.65)	290.50	0.21	23.28
T_3	8.34 (16.77)	11.67 (19.96)	15.00 (22.78)	18.34 (25.34)	1545.76	0.74	19.86	6.00 (14.17)	12.50 (20.70)	17.50 (24.72)	210.00	0.15	16.83
T_4	6.67 (14.96)	11.67 (19.96)	15.00 (22.78)	20.00 (26.55)	1510.79	0.72	19.40	6.00 (14.17)	14.50 (22.37)	19.00 (25.83)	231.00	0.17	18.51
T_5	8.34 (16.77)	15.00 (22.78)	21.67 (27.73)	26.67 (31.08)	2006.67	0.96	25.73	7.50 (15.89)	15.00 (22.78)	20.75 (27.09)	252.00	0.18	20.19
T_6	18.34 (25.34)	26.67 (31.08)	38.34 (38.24)	46.67 (43.07)	3646.18	1.74	46.67	13.75 (21.76)	27.50 (31.62)	39.00 (38.63)	474.25	0.34	38.00
T_7	8.34 (16.77)	15.00 (22.78)	20.00 (26.55)	23.33 (28.87)	1948.36	0.93	25.00	7.50 (15.89)	16.00 (23.57)	22.00 (27.96)	271.25	0.19	21.73
T_8	8.34 (16.77)	16.67 (24.09)	23.33 (28.87)	26.67 (31.08)	2176.04	1.04	27.85	8.75 (17.20)	17.50 (24.72)	24.00 (29.32)	299.25	0.21	23.98
T_9	10.00 (18.43)	16.67 (24.09)	20.00 (26.55)	26.67 (31.08)	2123.59	1.01	27.20	8.00 (16.42)	18.00 (25.09)	23.00 (28.65)	297.50	0.21	23.84
T_{10}	10.00 (18.43)	18.34 (25.34)	23.33 (28.87)	30.00 (33.20)	2350.86	1.12	30.07	9.00 (17.45)	20.00 (26.55)	24.50 (29.66)	327.25	0.23	26.22
T_{11}	10.00 (18.43)	15.00 (22.78)	20.00 (26.55)	16.67 (24.09)	1965.85	0.94	25.24	9.00 (17.45)	19.00 (25.83)	25.00 (29.99)	318.50	0.23	25.52
S.Em	0.42	0.72	2.39	1.86				2.12	1.88	3.12			
CD at 5 %	1.05	1.56	4.96	3.92				4.60	4.05	6.68			

Figures in the parentheses are arcsine transformed values.

Table 3. Effect of varietal composite on grain and fodder yield of finger millet

Tr. No.	September 2020		September 2021		Pooled mean		Yield increase over susceptible check (%)
	Grain yield (kg/ha)	Fodder yield (kg/ha)	Grain yield (kg/ha)	Fodder yield (kg/ha)	Grain yield (kg/ha)	Fodder yield (kg/ha)	
T_1	2340	4721	2135	4412	2238	4567	18.26 (25.29)
T_2	2355	4710	2075	4316	2215	4513	17.07(24.40)
T_3	2410	4913	2150	4437	2280	4675	20.51 (26.92)
T_4	2398	4896	2184	4465	2291	4681	21.09 (27.33)
T_5	2230	4640	2026	4192	2128	4416	12.47 (20.67)
T_6	1980	4121	1804	4015	1892	4068	00.00 (0.77)
T_7	2195	4574	2019	4246	2107	4410	11.36 (19.69)
T_8	2295	4676	2108	4197	2202	4437	16.36 (23.85)
T_9	2285	4670	2087	4208	2186	4439	15.54 (23.21)
T_{10}	2290	4650	2149	4215	2220	4433	17.31 (24.58)
T_{11}	2418	4930	2189	4505	2304	4718	21.75 (27.79)
S. Em					84.50	168	3.46
CD at 5 %					179.00	351	7.06

Figures in the parentheses are arcsine transformed values.

Discussion

The present study demonstrated that finger millet leaf blast incidence was effectively controlled by couple of sprays of tricyclazole 75 % WP, which caused a sharp decrease in the disease epidemic curve. Similar findings were reported by previous researchers who found tricyclazole was superior to other fungicides as an effective measure in controlling leaf, neck and finger blast (17). An earlier study highlighted the efficacy of chemical treatments, including propiconazole, azole + trifloxystrobin, tricyclazole + mancozeb, tricyclazole, isoprothiolane, azoxystrobin + difenoconazole, carbendazim + mancozeb and carbendazim, in controlling all types of blast disease (12).

Culture composites, particularly pre-released cultures pooled with resistant ones in a 1:1 ratio, delayed the progression of epidemics and slowed their spread compared to fungicide treatments. Researchers found that rice mixtures containing 66 % resistant component lines were sufficient to control *P. oryzae* (18). Similarly, in this study, neck and finger blast epidemics were effectively managed by cultivar mixture at both 1:1 and 2:1 ratio, which performed on par with each other. An earlier study demonstrated that a 1:1 mixture of VL 149 and PRM 1 reduced neck blast incidence (0.84 %) and finger blast incidence (10.42 %) more effectively than individual varieties (10).

The current study also recorded high biomass and grain yield in both the fungicide treated plots and the culture mixtures in a 2:1 ratio, with no statistically significant difference between them. Generally, cultivar mixtures have been shown to enhance yield stability and reduce disease-related losses by leveraging barrier and frequency effects across various agro-ecosystems (19). Additionally, they have been effectively utilized to manage fungal diseases in wheat, including stripe rust (20), *Cephalosporium* stripe (21) and leaf rust (22).

Previous research highlighted that varietal mixtures in winter barley (*Hordeum vulgare*) can enhance productivity stability under unpredictable environmental conditions (23). Through the augmentation of genetic diversity in crops, bypassing the demands of long-term breeding programs, these mixtures strengthen resilience to environmental stresses, making them a valuable tool for sustainable cropping systems.

The results reaffirm that employing varietal mixtures as a form of diversification within crop species is both ecologically sound and effective in controlling diseases, particularly those caused by airborne pathogens. This scalable approach enhances the resilience of crop production systems across large areas. The lower disease incidence observed in susceptible plants within diverse mixtures, compared to monocultures or pure stands, highlights the significant potential of crop diversification in disease management.

The ability of varietal mixtures to stabilize yields and enhance resilience highlights their effectiveness in mitigating disease-related yield fluctuations. This contributes to more consistent and reliable crop production, even under variable environmental conditions. Managing diseases through the inherent resistance of plants-especially via varietal mixtures-is both economically and environmentally beneficial. The approach aligns with IDM principles for sustainable disease control and reinforces the suitability of varietal mixtures for organic farming systems.

Conclusion

Our findings demonstrate the effectiveness of varietal mixtures under field conditions and provide actionable insights for farmers and agricultural practitioners seeking sustainable and cost-effective disease management strategies. By leveraging the ecological benefits of plant diversity, this approach promotes a balanced and environmentally friendly farming practice that ensures long-term productivity and agricultural sustainability.

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Authors' contributions

The research was conceptualized by RM, while AM and BA were responsible for designing the experiments. Experimental materials were supplied by MV and SPT. Field experiments were carried out and data were collected by RM, VP and SK. RM and BA performed the data analysis and interpretation. The manuscript was drafted by SPT and RM.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical issues: None

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