Heliyon 10 (2024) e25327

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Effect of cultivar mixtures of Finger millet [*Eleusine coracana* L. Gaertn.] on blast [*Pyricularia grisea* (Cooke) Sacc.] disease development under field conditions

Rajesh Manickam [a,*], Sudha Appusami [b], Sharavanan Periyanna Thangavelu [c,1], Sivagamy Kannan [d], Nirmalakumari Angamuthu [c,1], A. Thanga Hemavathy [e], Balaji Thiruvaliperumal [f]

[a] *Department of Plant Pathology, Anbil Dharmalingam Agricultural College and Research Institute, Trichy, 620027, India*
[b] *Department of Millets, Tamil Nadu Agricultural University, Coimbatore, 641003, India*
[c] *Centre of Excellence in Millets, Tamil Nadu Agricultural University, Athiyandal, 606603, India*
[d] *Krishi Vigyan Kendra, Tirur, 602 025, India*
[e] *Department of Plant Breeding and Genetics, Anbil Dharmalingam Agricultural College and Research Institute, Trichy, 620 027, India*
[f] *Krishi Vigyan Kendra, Ramanathapuram, 623 536, India*

ARTICLE INFO

Keywords:
AUDPC
Blast resistance
Cultivar mixture
Cost-benefit
Yield

ABSTRACT

The study aimed to assess the impact of different combinations of cultivar mixtures on finger millet blast epidemics without affecting yield. The research employed Disease Progress Curves (DPCs) such as AUDPC, rAUDPC, and sAUDPC to evaluate leaf, neck and finger blast epidemics' severity at various time intervals. Treatments involved mixtures of pre-released cultures and commercial varieties, combined with resistant cultivars in ratios of 1:1 and 2:1 to combat blast disease. These mixtures were compared with monoculture performances (resistant and susceptible checks) and fungicide treatments. The mixture of pre-released cultures (TNEc 1285 + TNEc 1294 + TNEc 1310) combined with the resistant cultivar GE4449 at a 1:1 ratio demonstrated the most significant impact in reducing the Area Under Disease Progressive Curve (AUDPC) values for all three blast types while maintaining consistent yield. This treatment exhibited results comparable to fungicide (Tricyclazole 75% WP) sprays across trials conducted from September to December in both 2020 and 2021. Economically, the cost-benefit ratio favoured the culture composite despite its delayed onset and slower progression during disease epidemics under field conditions. The mixture of cultures demonstrated sustainable yield without requiring significant additional input costs or frequent fungicidal application in both trial periods. This suggests a promising and cost-effective approach to managing finger millet blast epidemics while maintaining yield stability in agricultural practices.

* Corresponding author.
E-mail addresses: mrajeshpath@yahoo.co.in, rajesh.m@tnau.ac.in (R. Manickam), sudhaa1981@gmail.com (S. Appusami), pathsaran75@rediffmail.com (S.P. Thangavelu), ksivagamy@yahoo.com (S. Kannan), anirmalaikumari@yahoo.com (N. Angamuthu), hemavathytnau@gmail.com (A. Thanga Hemavathy), alwartbalaji@gmail.com (B. Thiruvaliperumal).
[1] Address (During work carried out): Centre of Excellence in Millets, Tamil Nadu Agricultural University, Athiyandal – 606 603.

https://doi.org/10.1016/j.heliyon.2024.e25327
Received 10 June 2023; Received in revised form 10 December 2023; Accepted 24 January 2024
Available online 7 February 2024

1. Introduction

The context outlined emphasizes the significance of finger millet (*Eleusine coracana* L. Gaertn) as a nutritious cereal crop that is particularly vital in addressing nutritional deficiencies and food insecurity prevalent in many developing nations, notably India. Despite its nutritional advantages over major cereals like rice and wheat, finger millet is a good source of minerals, proteins (7–14%) and gluten-free amino acids [1]. Finger millet grown in more than 25 nations of Africa and Asia continent, it makes around 12% of the world's millet area [2]. In field conditions, it faces significant challenges due to various diseases, particularly fungal infections like blast, brown spot, sheath blight, foot rot, green ear and smut diseases [3]. Among these, finger millet blast caused by the fungus *Pyricularia grisea* (formerly *Pyricularia oryzae*) significantly impacts crop yield, affecting all growth stages of the plant and leading to severe reductions in grain output and biomass, sometimes up to 80–100% [4,5]. The disease manifests in various parts of the plant, including leaves, necks and grains [6], causing lesions and discoloration that can ultimately lead to complete drying of the affected parts and a decrease in seed size and test weight [7] (see Figs. 1 and 2).

Smallholder farmers, especially those reliant on rain-fed agriculture, face challenges in managing finger millet diseases due to limited resources, making the use of fungicides economically unfeasible. Additionally, the pathogen's ability to generate new virulent strains quickly overcomes existing resistance measures [8]. The concept of employing variety mixtures for disease management is highlighted as a potential strategy. Variety mixtures offer functional diversity that can help restrict pathogen epidemics and potentially increase yield stability, as observed in other crops [9] especially cereals [10]. The study aims to investigate and provide evidence supporting the effectiveness of functional diversity against pathogens by using disease progression curves as a measurement scale for disease epidemics across different treatments.

The primary objectives of the study are as follows.

1. To establish evidence for the concept of functional diversity in combating pathogens, building upon earlier studies conducted in various crops.
2. To utilize disease progression curves as a metric to quantify and compare disease epidemics among different treatments, particularly focusing on the impact of variety mixtures in managing finger millet blast.

This research direction aims to contribute valuable insights into sustainable and effective strategies for managing finger millet blast, especially in resource-constrained agricultural settings, by exploring the potential of variety mixtures and their impact on disease control and crop yield stability.

2. Materials and methods

2.1. Treatment design

The experiments were conducted in September to December 2020 and 2021 at the same location, the Centre of Excellence in Millets, located at the coordinates 12°23′N, 70°02′E, with an elevation of 280 m above sea level, within the premises of the Tamil Nadu Agricultural University in Athiyandal, Tamil Nadu, India.

Eleven distinct treatments were established, comprising mixtures and monoculture variations. These treatments consisted of combinations involving the commercial variety CO15 in conjunction with the local variety, as well as resistant cultures (such as

Fig. 1. Finger millet leaf, neck and finger/panicle blast symptoms under field condition.

Fig. 2. Field view of integrated management of finger millet blast disease.

GE4449) paired with pre-released cultures (TNEc 1285, TNEc 1294, TNEc 1310) in ratios of 1:1 and 2:1. Monoculture treatments included both released and pre-released cultures, along with tests conducted on resistant and susceptible varieties in their response to finger millet blast.

The final analysis involved comparing the efficacy of cultural composite treatments with recommended fungicide application strategies. Specifically, the fungicide recommendation comprised two sprays of tricyclazole 75% WP at a rate of 500 g per hectare during the maximum tillering and heading stages of finger millet growth.

By assessing these different treatments, the research aimed to evaluate the effectiveness of various cultivar mixtures, monocultures and fungicide applications in managing finger millet blast under natural disease pressure conditions prevalent during the specified seasons and location. This assessment would provide valuable insights into potential strategies for mitigating the impact of the disease on finger millet crop yield and overall agricultural productivity.

2.2. Treatment details

T_1	–	Released variety (CO15) + GE4449 (Resistant Check) 1:1 ratio
T_2		Released variety (CO15) + GE4449 (Resistant Check) 2:1 ratio
T_3	–	Pre-released cultures (TNEc 1285 + TNEc 1294 + TNEc 1310) + GE4449 1:1 ratio
T_4		Pre-released cultures (TNEc 1285 + TNEc 1294 + TNEc 1310) + GE4449 2:1 ratio
T_5	–	GE4449 sole crop (Resistant Check)
T_6	–	*Udara mallike* (Susceptible Check)
T_7	–	CO15 sole crop
T_8	–	TNEc 1285 sole crop
T_9	–	TNEc 1294 sole crop
T_{10}	–	TNEc 1310 sole crop
T_{11}	–	Two spray of fungicide tricyclazole75% WP @ 0.2%

The experimental setup followed a randomized block design, incorporating three replicates for each treatment. The sowing of crops occurred in September for both the 2020 and 2021 seasons, utilizing a spacing arrangement of 25 × 10 cm between seeds, which aligned with typical agricultural practices prevalent in the region. A singular application of nitrogen was administered at the commencement of tillering, around the vegetative growth stage of the finger millet crop. Notably, no fungicide treatments were employed throughout the entire growth period of the crop, except for comparison checks. This experimental design aimed to simulate real agricultural conditions and practices commonly observed in the region, enabling an evaluation of the efficacy of different treatments, including cultivar mixtures and monocultures, in managing finger millet blast under natural disease pressure without the use of fungicides.

2.3. Disease scoring and Percent Disease Index calculation

The assessment of leaf blast incidence and the Percent Disease Index (PDI) was conducted at weekly intervals during the early stages of crop growth, specifically between 14 and 42 days after sowing. Upon the detection of blast incidence, a treatment involving the application of the fungicide Tricyclazole 75% WP at a 0.2% spray concentration was administered at both the tillering stage (25 days after sowing) and the flowering stage (55–60 days after sowing). Throughout the vegetative growth phase, observations of leaf blast incidence were recorded on days 14, 21, 28, 35, and 42 after sowing. This evaluation utilized a 1–9 scale for assessment, where a score of 9 denoted complete susceptibility, and a score of 1 indicated complete resistance to the disease. Additionally, observations for neck blast incidence were carried out during the flowering phase on days 70, 77, 84, and 91 after sowing. Furthermore, assessments for finger/panicle blast incidences were conducted during the maturity stages on days 91, 98, and 105 after sowing. This meticulous and comprehensive evaluation, conducted at various stages of crop growth, aimed to track the progression of blast disease in different parts of the finger millet plant (leaves, neck, and fingers/panicles) and assess the effectiveness of the fungicide treatment in managing the incidence and severity of the disease.

2.4. Standard evaluation system (SES) for leaf blast [11]

Score	Description
1	Small brown specks of pinhead size without sporulating centre
2	Small roundish to slightly elongated, necrotic grey spots, about 1–2 mm in diameter with a distinct brown margin and lesions are mostly found on the lower leaves
3	Lesion type is the same as in scale 2, but significant numbers of lesions are on the upper leaves
4	Typical sporulating blast lesions, 3 mm or longer, infecting less than 2% of the leaf area
5	Typical blast lesions infection in 2–10% of the leaf area
6	Blast lesions infecting 11–25% leaf area
7	Blast lesions infecting 26–50% leaf area
8	Blast lesions infecting 51–75% leaf area
9	More than 75% leaf area affected

$$\text{Neck blast }(\%) = \frac{Number\ of\ infected\ panicles}{Total\ number\ of\ panicles} X100$$

[12].

$$\text{Finger blast }(\%) = \frac{Number\ of\ infected\ panicles}{Average\ no.\ offingers/plant \times Total\ number\ of\ panicles} \times 100$$

[12].

2.5. Disease progress curves calculation

The calculation of the Area Under Disease Progress Curve (AUDPC) and the scale of susceptibility to blast (sAUDPC) values is essential for comparing disease levels among various culture composites in both pure stands and in mixtures, in conjunction with standard fungicide treatment. These values provide quantitative measures to assess the severity and progression of the disease over time. The AUDPC is calculated based on disease severity data collected at multiple time points during the course of the disease. It involves summing the individual areas of trapezoids formed by plotting disease severity against time. This calculation quantifies the overall disease severity experienced by each treatment over the entire observation period.

On the other hand, the sAUDPC (scale of susceptibility to blast) is derived from the AUDPC and represents a standardized measure that allows for a more comparable assessment of disease severity among different treatments, considering their varying disease progress curves. The method used for these calculations likely follows the protocols and formulas established by Ref. [13] for AUDPC and [14] for sAUDPC. These methodologies would involve mathematical calculations based on disease severity data recorded at specified time intervals, allowing researchers to quantify and compare the disease progression and susceptibility among different treatments, including mixtures, pure stands, and fungicide-treated samples.

3. Economic appraisal (cost-benefit ratio) of treatments

The economic analysis aimed to evaluate the cost-effectiveness and profitability of each treatment by conducting partial budgeting. This method assesses the economic impact of treatments by considering the costs and returns associated with various agricultural practices. Total returns were calculated based on the combined value of marketable grain and fodder yields obtained from each treatment. The increase in yield attributable to the treatments, compared to a control or baseline, was considered as the treatment effect.

Partial budgeting involves comparing the additional costs incurred due to the treatments against the additional returns or benefits generated. The costs typically considered in this analysis include expenses related to land preparation, sowing, weeding, fertilizer application, irrigation and harvesting. These costs are deducted from the total returns to determine the net benefit or profit obtained from each treatment. This approach provides insights into the profitability of different treatments by accounting for the additional costs incurred and the resulting increase in yields or other benefits. By assessing the economic implications of each treatment, researchers can make informed decisions regarding their cost-effectiveness and potential impact on overall profitability in agricultural practices. The methodology adopted for this economic analysis follows guidelines or procedures outlined by Ref. [15] in assessing the economic viability and profitability of agricultural treatments. Benefit-cost ratio, was calculated as

$$\text{Benefit} - \text{Cost ratio} = \frac{Net\ Return\ (Rs.)}{Total\ variable\ cost\ (Rs.)} \times 100$$

3.1. Data analysis

The experimental data underwent statistical analysis following the established and commonly used method outlined by Ref. [16]. To evaluate the effects of different treatments, an analysis of variance (ANOVA) was conducted considering the randomized block design (RBD) utilized in the experiment. In preparation for the analysis, data related to leaf blast, neck blast, and finger blast were subjected to an arcsine transformation. This transformation is a common practice when dealing with proportional data (such as percentages or proportions) to stabilize variances and better meet the assumptions of normality required for ANOVA and other parametric statistical tests.

4. Results

4.1. Blast epidemics incidence

The finger millet leaf blast incidence, as measured by the Area Under Disease Progress Curve (AUDPC) values, showed different trends among the treatments in the trials conducted during the September 2020 and 2021. The chemical treatment, exhibited lower AUDPC values, recording 1577.33 and 1564.17 in the two respective years (Tables 1 and 2; Fig. 3). Notably, this treatment depicted a rapid decline in the disease epidemic curve following immediate spray at 25 days after sowing (DAS). In contrast, the treatment involving the pre-released cultures (TNEc 1285 + TNEc 1294 + TNEc 1310) combined with the resistant culture GE4449 at a 1:1 ratio (T3) showed higher AUDPC values, recording 1794.79 and 1760.83 in 2020 and 2021, respectively. Although this treatment demonstrated slower progress in disease epidemics compared to other treatments, it didn't show the abrupt decline in the epidemic curve seen in the chemical treatment (T11).

When analysing the relative AUDPC and susceptible rates, the chemical treatment (T11) consistently displayed lower values (0.563 and 0.559 for relative AUDPC, and 6.07 and 6.04 for susceptible rates in September 2020 and 2021, respectively) compared to other treatments (Tables 1 and 2; Fig. 3). These metrics suggest that the chemical treatment effectively controlled the disease progression, resulting in lower disease severity and susceptibility rates in both trial years. However, while the chemical treatment showed immediate effectiveness in reducing disease incidence, the culture composite treatment (T3) exhibited a slower but steadier progression in managing the disease epidemic without the sudden decline observed in the chemical treatment. The differences in the disease progression patterns between these treatments highlight varying strategies for disease management in finger millet, with the chemical treatment providing immediate suppression and the culture composite treatment demonstrating a more gradual and sustained effect.

The observations of neck and finger blast incidences displayed variations compared to the leaf blast disease progress in both the seasons of 2020 and 2021. Specifically, the treatment involving the pre-released cultures (TNEc 1285 + TNEc 1294 + TNEc 1310) combined with the resistant culture GE4449 at 1:1 ratio (T3) exhibited lower incidences of neck and finger blast. Similarly, the 2:1 ratio of the culture composite also demonstrated lower Area Under Disease Progress Curve (AUDPC) values for neck and finger blast incidences. These findings are reflected in Tables 3 and 4 and illustrated in Fig. 4.

4.2. Grain and fodder yield

The data from both trials indicate that the treatment involving Tricyclazole 75% WP applied in two sprays (T11) and the combination of pre-released cultures (TNEc 1285 + TNEc 1294 + TNEc 1310) with GE4449 at 2:1 ratio (T4) exhibited comparable higher mean grain yields in finger millet cultivation. Specifically, the mean grain yield of 2304 kg/ha was recorded in the Tricyclazole 75% WP treatment (T11), which was similar to the mean grain yield of 2291 kg/ha achieved in the treatment involving the combination of pre-released cultures (TNEc 1285 + TNEc 1294 + TNEc 1310) with GE4449 at both 1:1 and 2:1 ratios. These results, presented in

Table 1
Effect of finger millet leaf blast disease epidemics on varietal composite under field trial during September 2020.

Tr. No	Leaf blast PDI					AUDPC	rAUDPC	sAUDPC
	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS			
T1	52.50 (46.41)	68.33 (55.73)	70.00 (56.77)	69.29 (56.32)	59.17 (50.26)	1844.17	0.659	7.09
T2	52.50 (46.41)	70.00 (56.77)	77.50 (61.66)	74.29 (59.51)	61.67 (51.73)	1952.08	0.697	7.51
T3	46.25 (42.83)	64.17 (53.21)	73.75 (59.16)	67.86 (55.44)	55.00 (47.85)	1794.79	0.641	6.90
T4	47.50 (43.55)	65.00 (53.71)	74.38 (59.56)	68.57 (55.88)	55.83 (48.33)	1817.29	0.649	6.99
T5	51.25 (45.70)	67.50 (55.22)	76.25 (60.81)	72.14 (58.12)	65.00 (53.71)	1918.13	0.685	7.38
T6	72.50 (58.35)	82.50 (65.24)	88.33 (70.00)	86.88 (68.73)	80.71 (63.92)	2340.21	0.836	9.00
T7	57.00 (49.00)	70.71 (57.21)	84.38 (66.69)	81.43 (64.45)	72.50 (58.35)	2108.88	0.753	8.11
T8	59.00 (50.16)	73.57 (59.04)	86.88 (68.73)	85.71 (67.77)	80.00 (63.41)	2209.63	0.789	8.50
T9	57.00 (49.00)	72.14 (58.12)	87.50 (69.27)	82.14 (64.98)	77.50 (61.66)	2163.25	0.773	8.32
T10	59.00 (50.16)	73.57 (59.04)	87.50 (69.27)	82.86 (65.51)	79.17 (62.82)	2191.08	0.783	8.43
T11	59.00 (50.16)	75.00 (59.98)	61.67 (51.73)	40.00 (39.22)	38.33 (38.24)	1577.33	0.563	6.07
S.Em	2.13	2.86	2.51	2.19	2.38			
CD at 5%	4.56	6.18	5.29	4.72	5.06			

Figures in the parentheses are arcsine transformed values.
DAS – Days After Sowing.

Table 2
Effect of finger millet leaf blast disease epidemics on varietal composite under field trial during September 2021.

Tr. No	Leaf blast PDI					AUDPC	rAUDPC	sAUDPC
	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS			
T1	51.25 (45.70)	66.67 (54.71)	71.25 (57.55)	67.86 (55.44)	57.50 (49.29)	1821.04	0.650	7.03
T2	53.75 (47.13)	69.17 (56.25)	75.63 (60.39)	72.14 (58.12)	60.83 (51.24)	1919.58	0.686	7.41
T3	47.50 (43.55)	63.33 (52.71)	72.50 (58.35)	65.71 (54.14)	52.50 (46.41)	1760.83	0.629	6.80
T4	48.75 (44.27)	64.17 (53.21)	73.13 (58.75)	66.43 (54.57)	54.17 (47.37)	1786.25	0.638	6.90
T5	52.50 (46.41)	68.33 (55.73)	75.00 (59.98)	69.29 (56.32)	63.33 (52.71)	1893.75	0.676	7.31
T6	71.67 (57.82)	81.88 (64.78)	89.44 (71.01)	86.25 (68.21)	79.29 (62.90)	2331.32	0.833	9.00
T7	58.00 (49.58)	71.43 (57.67)	81.25 (64.32)	77.14 (61.41)	70.83 (57.29)	2059.67	0.736	7.95
T8	60.00 (50.75)	72.14 (58.12)	83.75 (66.20)	81.43 (64.45)	75.00 (59.98)	2133.75	0.762	8.24
T9	59.00 (50.16)	71.43 (57.67)	84.38 (66.69)	80.71 (63.92)	73.33 (58.89)	2118.79	0.757	8.18
T10	60.00 (50.75)	72.86 (58.58)	85.00 (67.19)	79.29 (62.90)	75.83 (60.53)	2135.42	0.763	8.24
T11	61.00 (51.33)	74.29 (59.51)	63.33 (52.71)	37.00 (37.45)	36.67 (37.25)	1564.17	0.559	6.04
S. Em	1.61	1.38	2.14	2.06	2.12			
CD at 5%	3.73	3.06	4.89	4.51	4.80			

Figures in the parentheses are arcsine transformed values.

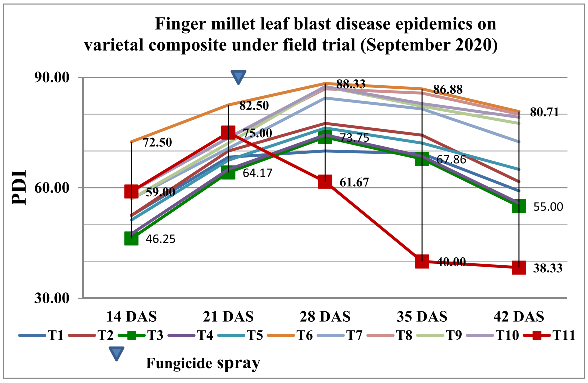

Fig. 3. Finger millet leaf blast disease epidemics on varietal composite under field trial (September 2020).

Table 5 and Fig. 5, highlight that these specific treatments resulted in higher grain yields of finger millet across both trials.

This indicates that the use of Tricyclazole 75% WP in two sprays and the combination of pre-released cultures with the resistant variety, particularly at both 1:1 and 2:1 ratios, had a positive impact on grain yield, demonstrating promising potential in enhancing the productivity of finger millet cultivation.

4.3. Economic analysis of treatments (partial budgeting)

The analysis highlighted a close association between disease epidemics and the treatments assessed. To evaluate the cost-effectiveness and profitability of these treatments, a cost-benefit ratio was calculated using the partial budgeting method. The culture composite treatments at 2:1 and 1:1 ratios exhibited higher cost-benefit ratios, specifically recording values of 1:1.51 and 1:1.52, respectively. These ratios indicate that for every unit of cost incurred, the treatments yielded a return of 1.51 and 1.52 units, respectively, demonstrating their economic viability and profitability. Notably, these treatments resulted in sustainable yields without incurring additional input costs, showcasing their potential as economically beneficial strategies for finger millet cultivation (as indicated in Table 6).

Following these culture composite treatments, the fungicide Tricyclazole 75% WP applied in two sprays displayed an effective check on disease epidemics in the field. This treatment recorded a cost-benefit ratio of 1:1.47, highlighting its cost-effectiveness in managing disease outbreaks and achieving a favorable economic return relative to the input costs. Overall, these results emphasize the economic advantages of the culture composite treatments, particularly at the 2:1 and 1:1 ratios, in terms of their cost-benefit ratios and sustainability in yielding profitable returns without incurring additional input costs.

Discussion

The use of Tricyclazole 75% WP in two sprays demonstrated a sudden decline in leaf blast incidence in this study, aligning with findings from Ref. [17], where it outperformed other fungicides in reducing all three types of finger millet blast. Additionally [18], suggested the effectiveness of chemical treatments like Tricyclazole, among others, in controlling leaf, neck, and finger blast. This

Table 3
Effect of finger millet neck and finger blast disease epidemics on varietal composite under field trial during September 2020.

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			
T1	10.00 (18.43)	13.33 (21.41)	16.67 (24.09)	20.00 (26.55)	1761.52	0.84	22.02	7.50 (15.89)	16.50 (23.96)	22.50 (28.31)	278.25	0.20	22.30
T2	13.33 (21.41)	16.67 (24.09)	20.00 (26.55)	23.33 (28.87)	2193.49	1.04	27.42	9.00 (17.45)	17.00 (24.34)	23.00 (28.65)	290.50	0.21	23.28
T3	6.67 (14.96)	10.00 (18.43)	13.33 (21.41)	16.67 (24.09)	1330.00	0.63	16.62	5.00 (12.92)	12.50 (20.70)	17.50 (24.72)	210.00	0.15	16.83
T4	6.67 (14.96)	10.00 (18.43)	13.33 (21.41)	16.67 (24.09)	1330.00	0.63	16.62	5.00 (12.92)	14.00 (21.96)	19.00 (25.83)	231.00	0.17	18.51
T5	6.67 (14.96)	13.33 (21.41)	23.33 (28.87)	26.67 (31.08)	1889.76	0.90	23.62	6.50 (14.76)	15.00 (22.78)	20.50 (26.91)	252.00	0.18	20.19
T6	20.00 (26.55)	26.67 (31.08)	40.00 (39.22)	46.67 (43.07)	3733.59	1.78	46.67	15.00 (22.78)	27.50 (31.62)	38.00 (38.04)	474.25	0.34	38.00
T7	6.67 (14.96)	13.33 (21.41)	20.00 (26.55)	23.33 (28.87)	1784.83	0.85	22.31	7.50 (15.89)	16.00 (23.57)	22.00 (27.96)	271.25	0.19	21.73
T8	10.00 (18.43)	16.67 (24.09)	23.33 (28.87)	26.67 (31.08)	2216.83	1.06	27.71	9.00 (17.45)	17.50 (24.72)	24.00 (29.32)	299.25	0.21	23.98
T9	10.00 (18.43)	16.67 (24.09)	20.00 (26.55)	26.67 (31.08)	2123.59	1.01	26.54	8.00 (16.42)	18.00 (25.09)	23.00 (28.65)	297.50	0.21	23.84
T10	10.00 (18.43)	20.00 (26.55)	23.33 (28.87)	30.00 (33.20)	2473.24	1.18	30.91	9.00 (17.45)	20.00 (26.55)	24.50 (29.66)	327.25	0.23	26.22
T11	6.67 (14.96)	13.33 (21.41)	20.00 (26.55)	16.67 (24.09)	1761.52	0.84	22.02	9.00 (17.45)	19.00 (25.83)	25.00 (29.99)	318.50	0.23	25.52
S.Em	0.46	0.69	2.43	1.82				2.15	1.85	3.05			
CD at 5%	1.03	1.45	5.16	3.98				4.86	4.07	7.16			

Figures in the parentheses are arcsine transformed values.

Table 4
Effect of finger millet neck and finger blast disease epidemics on varietal composite under field trial during September 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			
T1	13.33 (21.41)	20.00 (26.55)	23.33 (28.87)	26.67 (31.08)	2543.17	1.21	33.35	9.00 (17.45)	16.50 (23.96)	22.50 (28.31)	283.50	0.20	24.00
T2	10.00 (18.43)	16.67 (24.09)	23.33 (28.87)	26.67 (31.08)	2216.83	1.06	29.07	8.50 (16.94)	17.00 (24.34)	23.00 (28.65)	288.75	0.21	24.44
T3	10.00 (18.43)	13.33 (21.41)	16.67 (24.09)	20.00 (26.55)	1761.52	0.84	23.10	7.00 (15.34)	12.50 (20.70)	17.50 (24.72)	217.00	0.16	18.37
T4	6.67 (14.96)	13.33 (21.41)	16.67 (24.09)	23.33 (28.87)	1691.59	0.81	22.18	7.00 (15.34)	15.00 (22.78)	19.00 (25.83)	248.50	0.18	21.04
T5	10.00 (18.43)	16.67 (24.09)	20.00 (26.55)	26.67 (31.08)	2123.59	1.01	27.85	8.50 (16.94)	15.00 (22.78)	21.00 (27.26)	260.75	0.19	22.07
T6	16.67 (24.09)	26.67 (31.08)	36.67 (37.25)	46.67 (43.07)	3558.77	1.69	46.67	12.50 (20.70)	27.50 (31.62)	40.00 (39.22)	472.50	0.34	40.00
T7	10.00 (18.43)	16.67 (24.09)	20.00 (26.55)	23.33 (28.87)	2111.90	1.01	27.69	7.50 (15.89)	16.00 (23.57)	22.00 (27.96)	271.25	0.19	22.96
T8	6.67 (14.96)	16.67 (24.09)	23.33 (28.87)	26.67 (31.08)	2135.25	1.02	28.00	8.50 (16.94)	17.50 (24.72)	24.00 (29.32)	297.50	0.21	25.19
T9	10.00 (18.43)	16.67 (24.09)	20.00 (26.55)	26.67 (31.08)	2123.59	1.01	27.85	8.00 (16.42)	18.00 (25.09)	23.00 (28.65)	297.50	0.21	25.19
T10	10.00 (18.43)	16.67 (24.09)	23.33 (28.87)	30.00 (33.20)	2228.49	1.06	29.22	9.00 (17.45)	20.00 (26.55)	24.50 (29.66)	327.25	0.23	27.70
T11	13.33 (21.41)	16.67 (24.09)	20.00 (26.55)	16.67 (24.09)	2170.18	1.03	28.46	9.00 (17.45)	19.00 (25.83)	25.00 (29.99)	318.50	0.23	26.96
S. Em	0.43	0.76	2.20	2.11				2.08	2.12	2.58			
CD at 5%	1.01	1.59	5.03	4.68				4.61	4.87	3.11			

Figures in the parentheses are arcsine transformed values.

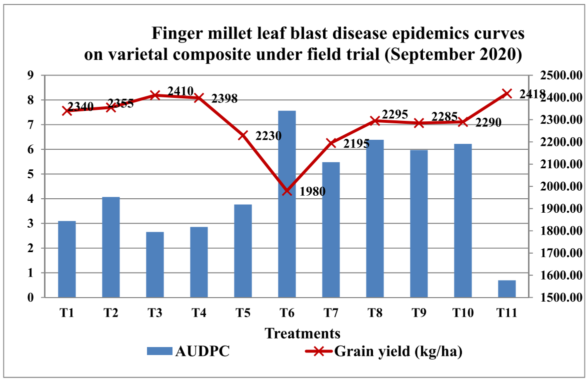

Fig. 4. Finger millet leaf blast disease epidemics curves on varietal composite under field trial (September 2020).

Table 5
Effect of treatment on grain and fodder yield of finger millet under field condition during September 2020 and 2021.

Trt. No.	September 2020		September 2021		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.

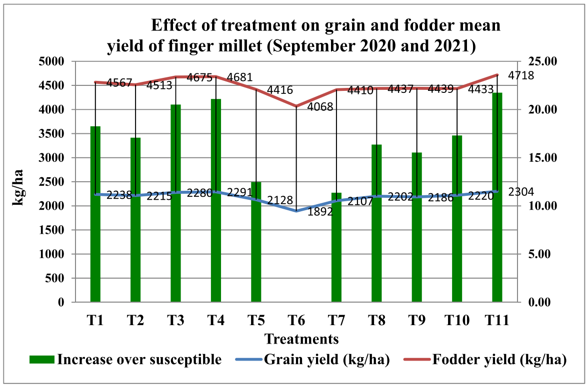

Fig. 5. Effect of treatment on grain and fodder mean yield of finger millet (September 2020 and 2021).

study highlights the effectiveness of a culture composite at a 1:1 ratio in delaying and slowing down disease progress, similar to findings by Ref. [19] in a rice mixture that effectively controlled *Pyricularia oryzae*.

Moreover, our observations regarding the comparable control of neck and finger blast by culture composites at both 1:1 and 2:1 ratios align with previous studies showing the efficacy of specific mixtures or combinations in reducing blast disease incidences in various crops. The economic analysis further reinforces the efficacy of culture composite treatments, demonstrating higher cost-benefit ratios and sustainable yields, indicating their potential as economically beneficial strategies for finger millet cultivation. This echoes

Table 6
Calculation of cost benefit ratio of treatments (Partial budgeting method).

Treatment	Fixed cost (Rs.)	Treatment (Chemical + Spray) cost (Rs.)	Total cost (Rs.)	Grain Yield (kg/ha)	Straw Yield (kg/ha)	Gross Return (Rs.)	Net Return (Rs.)	Cost Benefit ratio
T_1	47,500	–	47,500	2238	4567	70,550	23,050	1:1.48
T_2	47,500	–	47,500	2215	4513	69,835	22,335	1:1.47
T_3	47,500	–	47,500	2280	4675	71,906	24,406	1:1.51
T_4	47,500	–	47,500	2291	4681	72,240	24,740	1:1.52
T_5	47,500	–	47,500	2128	4416	67,152	19,652	1:1.41
T_6	47,500	–	47,500	1892	4068	59,811	12,311	1:1.25
T_7	47,500	–	47,500	2107	4410	66,518	19,018	1:1.40
T_8	47,500	–	47,500	2202	4437	69,372	21,872	1:1.46
T_9	47,500	–	47,500	2186	4439	68,909	21,409	1:1.45
T_{10}	47,500	–	47,500	2220	4433	69,909	22,409	1:1.47
T_{11}	47,500	1625	49,125	2304	4718	72,643	23,518	1:1.47

findings from studies like [20–22] across different crops, showcasing the potential of varied treatments and mixtures in managing diseases and enhancing crop productivity while ensuring economic feasibility and sustainability. Overall, these diverse studies collectively emphasize the effectiveness of cultivar mixtures in mitigating finger millet blast, providing insights into potential strategies for disease management and sustainable agricultural practices.

Conclusion

Our findings strongly support the notion that intra-specific crop diversification, particularly through varietal mixtures, presents an ecologically sound approach to disease control, particularly for airborne pathogens. The results indicate that this approach can be highly effective across a broad area, contributing significantly to the sustainability of grain production. Our observations highlight that susceptible plants experienced significantly lower disease incidences when grown within heterogeneous mixtures compared to monoculture or pure stands. Moreover, regarding yield, mixtures demonstrated a stabilizing effect and better resilience compared to pure stands, indicating that mixed cropping can buffer yield fluctuations more effectively.

The emphasis on managing diseases by harnessing the inherent capacity of plants within mixed cultures underscores the importance of utilizing the natural traits and resistance mechanisms present in diverse varieties. Our study indicates that growing a mixture of cultures is not only economically advantageous for minimizing disease-related losses but also environmentally friendly, promoting a more sustainable agricultural system. The utilization of varietal composites for disease management represents a crucial strategy within Integrated Disease Management (IDM) practices and holds a significant role in organic farming systems. Our research provides substantial evidence supporting the success of varietal mixtures under field conditions, reaffirming the effectiveness and importance of employing diverse varietal combinations as a practical and successful approach in disease management within agricultural systems.

Data availability statement

Data available as supplementary information - Data supporting this study are included within the article and/or supporting materials.

CRediT authorship contribution statement

Rajesh Manickam: Writing – original draft, Writing – review & editing, Methodology, Data curation, Conceptualization. **Sudha Appusami:** Writing – review & editing, Data curation. **Sharavanan Periyanna Thangavelu:** Methodology. **Sivagamy Kannan:** Resources, Formal analysis. **Nirmalakumari Angamuthu:** Resources, Conceptualization. **A. Thanga Hemavathy:** Resources. **Balaji Thiruvaliperumal:** Methodology.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Rajesh Manickam reports administrative support was provided by Tamil Nadu Agricultural University. Rajesh Manickam reports a relationship with Tamil Nadu Agricultural University that includes: employment. Rajesh Manickam has patent Nil pending to Nil. Rajesh Manickam, Sudha Appusami, Sharavanan Periyanna Thangavelu, Sivagamy Kannan Nirmalakumari Angamuthu A. Thanga Hemavathy and T. Balaji.

Acknowledgements

The authors wish to acknowledge the Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India for providing materials and facilities during the course of present study. No funding was received for this work.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e25327.

References

[1] A. Kumar, M. Metwal, S. Kaur, A.K. Gupta, S. Puranik, S. Singh, R. Yadav, Nutraceutical value of finger millet [*Eleusine coracana* (L.) Gaertn.], and their improvement using omics approaches, Frontiers in Plant Science 7 (2016) 934.

[2] T.K. Babu, R. Sharma, R.P. Thankur, H.D. Upadhyaya, P.N. Reddy, A.G. Girish, Selection of host differentials for elucidating pathogenic variation in *Magnaporthe grisea* populations adapted to finger millet (*Eleusine coracana* L.), Plant Disease 99 (12) (2015) 1784–1789, https://doi.org/10.1094/PDIS-10-14-1089-RE.

[3] P. Preethi, M.S. Sharada, C.R. Divya, Leaf blast disease in finger millet [*Eleusine coracana* (L.) Gaertn.] caused by *Bipolaris sorokiniana* Sacc.: a histopathological study, Journal of Plant Disease Protection 127 (6) (2020) 899–903, https://doi.org/10.1007/s41348-020-00355-5.

[4] M.A. Mgonja, J.M. Lenne, E. Manyasa, E. S, Sreenivasaprasad Finger Millet Blast Management in East Africa. Creating Opportunities for Improving Production and Utilization of Finger Millet, Patancheru: International Crops Research Institute for the Semi-Arid Tropics, 2007.

[5] M.M. Dida, C.A. Oduori, S.J. Manthi, M.O. Avosa, E.O. Mikwa, H.F. Ojulong, A. D, Odeny Novel sources of resistance to blast disease in finger millet, Crop Science 61 (1) (2021) 250–262, https://doi.org/10.1002/csc2.20378.

[6] A. Bhatta, A. Sharma, P. Gautam, B. Subedi, M. Paudel, K.P. Mishra, Resistant and susceptible response of finger millet to seedling, International Journal of Information Research and Review 4 (12) (2017) 4804–4809.

[7] G. Hunsigi, K.R. Krishna, Science of Field Crop Production; Finger Millet, New Delhi Oxford and IBH publishing Co Pvt. Ltd., 1998, p. 132.

[8] R. Khadka, S. Shrestha, H.K. Manandhar, Pathogenic variability and differential interaction of blast fungus (*Pyricularia grisea* SACC.) isolates with finger millet lines in Nepal, Nepal Journal of Science and Technology 14 (2) (2013) 17–24, https://doi.org/10.3126/njst.v14i2.10411.

[9] Y.Y. Zhu, H.R. Chen, J.H. Fan, Genetic diversity and disease control in rice, Nature 406 (2000) 718–722.

[10] M.S. Wolfe, J.A. Barrett, Can we lead the pathogen astray? Plant Disease 64 (1980) 148–155.

[11] T.K. Babu, R.P. Thankur, H.D. Upadhyaya, P.N. Reddy, R. Sharma, A.G. Girish, N.D. Sharma, Resistance to blast (*Magnaporthe grisea*) in a mini-core collection of finger millet germplasm, European Journal of Plant Pathology 135 (2) (2013) 299–311, https://doi.org/10.1007/s10658-012-0086-2.

[12] Prahlad Singh Netam, Ashwani Kumar Thakur, Prafull Kumar, R.S. Netam, Screening of finger millet (*Eleusine coracana*) varieties for resistant to blast (*Magnaporthe grisea*) disease in bastar district, Chhattisgarh, India, Int.J.Curr.Microbiol.App.Sci. 8 (12) (2019) 2664–2668, https://doi.org/10.20546/ijcmas.2019.812.311.

[13] J.E. Yuen, A. G, Forbes Estimating the level of susceptibility to *Phytophthora infestans* in potato genotypes, Phytopathology 99 (6) (2009) 782–786, https://doi.org/10.1094/PHYTO-99-6-0782. PMID: 19453239.

[14] G. Forbes, W. Pérez, J. Andrade Piedra, Field Assessment of Resistance in Potato to *Phytophthora Infestans*. Lima (Peru), International Potato Center (CIP), 2014, p. pp35.

[15] K.M. Jackson, J. Mafurah, Joseph, M. Nyongesa, Wambomba, ng'ang'a nancy cost benefit analyses in managing late blight through *Trichoderma asperellum* seed treatment and Ridomil® application on potato, Journal of Agricultural Science 12 (7) (2020) 32–52.

[16] K.A. Gomez, A.A. Gomez, Statistical Procedure for Agricultural Research, John Wiley and Sons, New York, 1984.

[17] G.K. Upamanya, R. Brahma, M. Choudhury, P. Deka, R. Sarma, Response of different variety of finger millet against diseases and evaluation of efficacy of fungicides against leaf blast, International Journal of Recent Science Research 10 (12) (2019) 36655–36658, https://doi.org/10.24327/ijrsr.2020.1012.4966.

[18] T.S.S.K. Patro, K.E. Georgia, S. Raj Kumar, N. Anuradha, U. Y. Sandhya Rani, Triveni Management of finger millet blast through new fungicides, International Journal of Chemical Studies 8 (3) (2020) 2341–2343.

[19] Bijender Kumar, J. Kumar, Management of blast disease of finger millet (*Eleusine coracana* L.) through fungicides, bioagents and varietal mixture, Indian Phytopathology 64 (3) (2011) 272–274.

[20] A. Nagaraj, Bijendra Kumar, T. Raguchander, A.K. Hota, T.S.S.K. Patro, P. Devaraje Gowda, Savitaekka, M.V.C. Gowda, Impact of disease management practices on finger millet blast and grain yield, Indian Phytopathology 65 (4) (2012) 356–359.

[21] H.E. Creissen, H. Tove, James KM Brown Jorgensen, Increased yield stability of field-grown winter barley (*Hordeum vulgare* L.) varietal mixtures through ecological processes, Crop Protection 85 (2016) 1–8, https://doi.org/10.1016/j.cropro.2016.03.001.

[22] S.B. Gurung, N.B. Dhami, S. Subedi, J. Shrestha, Management of blast disease of finger millet (*Eleusine coracana* L. Gaertn) caused by *Pyricularia grisea* under field conditions in Dolakha, Nepal Journal of Agriculture and Natural Resources 5 (1) (2022) 89–104, https://doi.org/10.3126/janr.v5i1.50621.