



Impact of frontline demonstrations on integrated foot rot management and productivity of black pepper (*Piper nigrum* L.)

Kedarnath*, T. J. Ramesha, R. Rashmi and Mallikarjuna Lingappa

ICAR-Krishi Vigyan Kendra (Dakshina Kannada), Karnataka Veterinary Animal and Fisheries University Bidar, 575 002, Karnataka, India

(Manuscript Received: 07-04-2025, Revised: 17-04-2026, Accepted: 05-06-2026)

Abstract

Foot rot of black pepper (*Piper nigrum* L.), caused by *Phytophthora capsici* Leonian, is a highly destructive disease that affects plants at all growth stages and is responsible for substantial plant mortality. As no completely resistant varieties are currently available, disease management relies largely on preventive measures. Although copper-based fungicides are permitted in organic production systems, their use should be minimized to meet the growing global demand for organic produce. To promote sustainable disease management, ICAR-Krishi Vigyan Kendra, Mangaluru, conducted 30 Frontline Demonstrations (FLDs) on integrated foot rot management in black pepper during 2019–20 to 2021–22 in Dakshina Kannada district. The demonstrated technology significantly reduced foot rot incidence to 9.80%, 9.10%, and 3.80% during the respective years, compared with 21.50%, 22.30%, and 11.30% under farmers' practices. Consequently, the demonstrations achieved an average yield of 14.18 q ha⁻¹, representing a 40.54% increase over farmers' practice (10.09 q ha⁻¹). The integrated management approach also improved economic returns, recording a gross return of ₹650,700 ha⁻¹, a net return of ₹492,244 ha⁻¹, and a benefit–cost ratio of 4.11, all of which were superior to those obtained under farmers' practices. The average technology gap, extension gap, and technology index were 73.80 q ha⁻¹, 4.09 q ha⁻¹, and 83.87%, respectively. These findings demonstrate the effectiveness of scientifically validated integrated disease management technologies in reducing foot rot incidence, enhancing productivity, and improving the economic viability of black pepper cultivation.

Keywords: Black pepper, foot rot, Arka microbial consortium, Arka Actinoplus

Introduction

Black pepper (*Piper nigrum* L.) is a perennial climbing woody vine belongs to the Piperaceae family, globally known as “King of Spices” reflecting its prominent role in international trade and widespread dietary and medicinal applications (Quijano-Abril *et al.*, 2006). It is a versatile spice valued for its distinct aroma and flavour, and has long occupied an important place in India's agricultural landscape (Nair, 2004). India ranks fifth among the world's leading producers and exporters of black pepper, with Karnataka contributing a substantial share of the country's total production (Anon, 2023). Historically, Karnataka has been considered as the major centre of black pepper

production in India, accounting for around 69% of the country's area and production (Anon, 2023). Karnataka along with Kerala contribute the 92.64% of the nation's black pepper production (Anon, 2023). In recent years, the cultivation of black pepper has been severely affected by the rapid and wide spread occurrence of foot rot disease caused by the oomycete's fungus *Phytophthora capsica* L. The fungi poses a major threat to both yield and productivity of the crop (Anandaraj & Sarma, 1995; Nair, 2004). This disease infects all parts of the pepper plant at various growth stages (Mathew *et al.*, 2005). Efforts to manage *Phytophthora* spp. through several practices like pre-plant soil fumigation and the use of host plant resistant have

*Corresponding Author: kedarnath.govin@gmail.com

proven largely ineffective due to polycyclic nature of fungi (Umaerus *et al.*, 1983). Presently, widespread application of pesticides remains as the main focus of the management strategy. In this context, continuous application of chemical pesticides poses environmental pollution, adverse health effects, and the development of pathogen resistance (Gisi & Cohen, 1996). Farmers often lack adequate scientific knowledge of black pepper cultivation and consequently incur substantial economic losses due to various biotic stresses. Therefore, there is an urgent need to enhance crop productivity through improved plant and soil health management. This can be achieved by integrating microbial consortia and micronutrient mixtures with the recommended package of practices, thereby strengthening crop resilience, improving nutrient availability, reducing disease incidence, and enhancing overall productivity and profitability. Arka Microbial Consortium and Arka Actinoplus are carrier-based formulations containing beneficial microorganisms such as *Azotobacter* spp., *Bacillus* spp., *Pseudomonas* spp., and actinobacterial strains (in Arka Actinoplus). These microbial consortia contribute to biological nitrogen fixation, phosphorus and zinc solubilization, and overall enhancement of plant growth and health. In addition, the micronutrient mixture *IISR Pepper Special* supplies essential secondary and micronutrients, including magnesium, zinc, and boron, which are critical for optimum growth, productivity, and disease tolerance in black pepper.

Considering these benefits, Frontline Demonstrations (FLDs) serve as an important extension tool for transferring proven technologies to farmers at the grassroots level and facilitating the large-scale adoption of scientific innovations. FLDs provide a highly effective platform for direct interaction between scientists and farmers, with scientists actively involved in the planning, implementation, monitoring, and evaluation of demonstrations conducted under farmers' field conditions. With this background, ICAR–Krishi Vigyan Kendra, Dakshina Kannada, Mangaluru, conducted Frontline Demonstrations on black pepper cultivation with the objective of promoting

scientific crop production technologies, including the application of Arka Microbial Consortium, Arka Actinoplus, and the micronutrient mixture *IISR Pepper Special*. The demonstrations aimed to improve plant and soil health, enhance productivity, manage foot rot disease effectively, and facilitate the wider dissemination and adoption of these technologies among black pepper growers.

Materials and Methods

Frontline Demonstrations (FLDs) were conducted by ICAR–Krishi Vigyan Kendra, Dakshina Kannada, Mangaluru, in selected farmers' fields across identified cluster villages of Dakshina Kannada district during 2019–20 to 2021–22 (Fig.1). Demonstrations were established in 8–10-year-old plantations of the black pepper variety *Panniyur-1* that were affected by foot rot disease. A total thirty demonstrations were conducted with the active participation of farmers, aiming to assess the effectiveness of the microbial consortium *viz.*, Micronutrient mixture (*IISR Pepper Special*), Arka microbial consortium and Arka Actinoplus against foot rot disease of black pepper.

Specific Locations:

1. Location 1st (2019-20): Kabaka (87m MSL) and Balnadu (98 m MSL) villages, Puttur taluk (12°47'27.9"N, 75°09'20.9"E and 12°74'62"N, 75°16'57"E, respectively)

2. Location 2nd (2020-21): Nyayatharpu (96m MSL) village, Belthangady taluk (12°92'06"N, 75°26'83"E)



Fig. 1. Black pepper farm (8-years old plantation) at Nyayatarpu village of Belthangady taluk.

3. Location 3rd (2021-22): Harekal (24m MSL) village, Ullal taluk (12.8510° N, 74.9174° E)

Each year, an area of two hectares was allocated for scientific technology demonstrations in black pepper crop, with farmers practices as control. The selection of technologies for demonstration was carried out using a participatory rural appraisal approach. A group of progressive black pepper farmers were identified based on their enthusiastic involvement and the insights they provided during the survey and interactive sessions. Before implementation, capacity development programmes were conducted and the critical inputs such as IISR pepper special, Arka microbial consortium (AMC) and Arka Actinoplus were distributed. The comparative features of technology intervention and traditional farming practices are outlined (Table 1).

IISR Pepper special is a crop specific micronutrient mixture contains potassium (8-10%), magnesium (2-3%), zinc (5-6.5%) and boron (2-3.5%).

Observations recorded

Disease incidence Farmers plots with uniform foot rot infection were selected for the study. Foot rot incidence was calculated by using below mentioned formula

$$\text{Foot rot incidence} = \frac{\text{Total No. of wilted plants}}{\text{Total No. of plants observed}} \times 100$$

Per cent disease index (PDI)

The disease severity was analysed 30 days after post application of treatments. Per cent disease indexed visually and calculated based on disease severity scale (0-5 scale) given by Sunwoo *et al.*, 1996. Disease severity scoring is as follows:

Table 1. Efficacy of technology interventions and farmers practices under FLD on integrated foot rot management in black pepper

Sl. No.	Particulars	Technological interventions in FLD	Farmers Practice	Gap
1.	Variety/Hybrid	Panniyur 1	Panniyur 1	No gap
2.	Spacing	2.7 m × 2.7 m	2.7 m × 2.7 m	No gap
3.	Application of lime	Based on soil test (200–300-gram palm ⁻¹)	No application	Full gap
4.	Farm yard manure	12 kg palm ⁻¹	10 kg palm ⁻¹	Partial gap
5.	Fertilizer dose	N:P:K (100:40:140 g palm ⁻¹ year ⁻¹)	Injudicious use of complex fertilizer application	Partial gap
6.	Micronutrients application	Application of pepper special @ 5 g L ⁻¹ during pre-flowering (fortnight of May) and post flowering period (Fortnight of July)	No	Full gap
7.	Microbial consortium or use of biocontrol agents	Soil drenching (3 litre veins ⁻¹) of AMC @ 20 g L ⁻¹ during June and August, soil drenching (3 litre veins ⁻¹) of Arka Actinoplus @ 20 g L ⁻¹ during September.	No	Full gap
8.	Drainage	Good drainage system	Non adoption of scientific drainage system	Partial gap
9.	Plant protection	Deployment of IDM strategies based on local needs.	Non-adoption of IDM practices	Full gap

Application of Arka microbial consortium A solution was prepared by dissolving six kg of AMC and 750 grams of jaggery in 300 litres of water. This solution was applied @ 3 L per plant-1 near the root zone of each vine.

Arka Actinoplus is a microbial formulation containing actinobacterial strains. These actinomycetes possess the ability to solubilize phosphorus and zinc, produce phytohormone, and secrete cellulase and chitinase enzymes.

Score	Lesion size
0	No noticeable symptoms present
1	Slightly wilted leaves with brownish lesions forming on the stem
2	Disease affects approximately 30-50% of the vines
3	Around 50-70 % of the vines shows disease symptoms
4	70-90 % of the vines exhibit wilting symptoms
5	Completely dead vine

The per cent disease index was analysed by using formula (Wheeler, 1969)

$$PDI = \frac{\text{Sum of individual disease ratings}}{\text{Total number of pepper vines observed} \times \text{Maximum disease rating}} \times 100$$

Yield and economics

Pepper yield (dry berries) recorded from the fields of technology demonstration and traditional farming plots by harvesting berries from individual vines. These yields were subsequently converted into quintals per hectares for comparative analysis. Appropriate statistical tools were used for data analysis. A comprehensive economic evaluation was conducted to assess the financial viability of the treatments. For estimation of cost of cultivation, the cost concepts were used. Based on the prevailing market prices the gross return was calculated and net returns were determined by subtracting total cultivation costs from gross returns.

To determine technology gap, extension gap and technology index, the formulas proposed by Choudhary *et al.*, (2021) were applied.

$$\text{Technology gap} = \text{Pi (Potential yield)} - \text{Di (Demonstration yield)}$$

$$\text{Extension gap} = \text{Di (Demonstration yield)} - \text{Fi (Farmers yield)}$$

$$\text{Technology index} = \frac{\text{Pi (Potential yield)} - \text{Di (Demonstration yield)}}{\text{Potential yield}} \times 100$$

Benefit cost ratio and per cent increase in yield were calculated by using the formula

$$\% \text{ increase in yield} = \frac{\text{Demonstration yield} - \text{Farmers practice yield}}{\text{Farmers practice yield}} \times 100$$

$$\text{Benefit cost ratio} = (\text{Gross income}) / (\text{Cost of cultivation})$$

The data on disease severity and yield on management of foot rot were analysed using paired T test with $P=0.05$ level of significance.

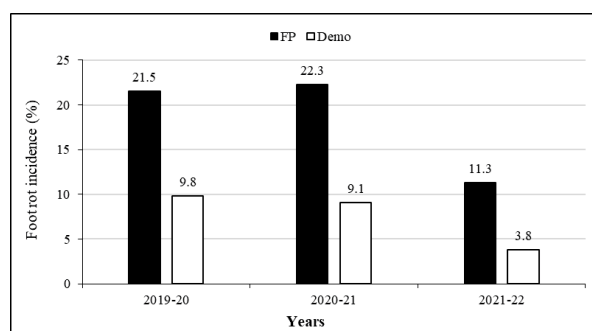
Results and Discussion

The present frontline demonstrations were conducted to evaluate the effectiveness of micronutrients and microbial consortia in combination with recommended packages of practices for the integrated management of foot rot disease and enhancement of yield in black pepper cultivation. Front-line demonstrations recorded the lowest foot rot incidence of 9.80%, 9.10%, and 3.80 % in the technology demonstrated plots in three consecutive years (2019-20 to 2021-22) compared to the highest incidence under farmers practices

(21.50%, 22.30% and 11.30% respectively) (Fig.2). The technology intervention plots exhibited a 68.21% lower disease index compared with farmers' practices (Table 2). Productivity analysis of the Frontline Demonstration (FLD) plots revealed higher yields of 15.38 q ha⁻¹ during 2019–20, 12.72 q ha⁻¹ during 2020–21, and 14.46 q ha⁻¹ during 2021–22, compared with 9.98 q ha⁻¹, 9.04 q ha⁻¹, and 11.26 q ha⁻¹, respectively, under farmers' practices. Overall, the demonstrated technology recorded an average yield increase of 40.54% over the traditional cultivation practices.

The results indicate that the integration of micronutrients and microbial consortia, namely Arka Microbial Consortium and Arka Actinoplus, significantly reduced the incidence and severity of foot rot disease while enhancing crop productivity. These findings are consistent with those of Veerendra Kumar and Saju (2023), who reported that the application of Arka Microbial of Veerendra Kumar and Saju (2023), who reported that the application of Arka Microbial Consortium during June and September was highly effective in managing foot rot disease in black pepper. Similarly, Panneerselvam *et al.* (2015) documented a reduction in disease incidence and demonstrated the antagonistic activity of actinobacteria against several plant

Fig 2. Efficacy of improved technologies of black pepper on foot rot disease incidence following technology demonstrations during 2019-20 to 2021-22 [FP: Farmers practice and Demo: Improved technology practice]



Paul *et al.* (2005) evaluated six strains of *Pseudomonas fluorescens* for their ability to suppress root rot in black pepper and rejuvenate infected seedlings. The bioagent strains increased total root biomass by 30–135%, thereby improving

plant vigour and disease tolerance. Comparable benefits of microbial inoculants have also been reported in other crops. Reddy and Parama (2018) observed improved yield attributes in turmeric following the application of Arka Actinoplus, while Panneerselvam *et al.* (2017) reported enhanced grain yield in rice.

The yield enhancement observed in the present study may be attributed to the establishment of a nutrient-rich rhizosphere environment by the microbial consortium, which improves nutrient availability and uptake. Ganeshamurthy *et al.* (2015) reported yield increases of 13–14% in several vegetable crops due to improved nutrient acquisition facilitated by microbial consortia. Furthermore, Priyadarshini *et al.* (2020) demonstrated that compost enriched with Arka Microbial Consortium enhanced seed production in French bean (*Arka Arjun*) and amaranth (*Arka Arunima*), while also improving soil fertility and overall crop productivity. These findings collectively support the role of microbial consortia and micronutrient supplementation in sustainable disease management and productivity enhancement in black pepper cultivation.

The economic analysis was performed on the basis of prevailing market prices. It was found that, across all the years, plots where technologies are demonstrated consistently yielded significantly higher net returns compared to those managed by traditional farmers practices. The technology demonstration plots generated net returns of Rs.3,91,224/- ha⁻¹, notably surpassing the Rs.2,40,690/- ha⁻¹ which was recorded from farmers practices (Table 3). The mean gross expenditure for the demonstration plots was Rs.1,50,849/- ha⁻¹, which was higher than the Rs.1,28,623/- ha⁻¹ incurred under farmers practice plots. In contrast, the average gross income from the demonstration plots reached Rs.5,42,073/- ha⁻¹, significantly exceeding the Rs.3,69,313/- ha⁻¹ earned from the farmers practice plots. Evaluation of the yield data indicated that the demonstration plots achieved an average incremental benefit-cost of 3.58, outperforming the 2.85 ratio recorded under traditional farmers practices. Similar findings have also recorded in pulses by Raj *et al.* (2013) and Chandra Ganesh (2010). Findings from Pagaria (2015) also affirm that identification, farming conditions, and targeted interventions has significantly contributed to enhanced productivity in demonstration plots.

Table 2. Performance of improved technologies of black pepper on foot rot disease severity and production

Treatments	Brown leaf spot PDI (60 DAT)			Yield (q ha ⁻¹)				
	2019-20	2020-21	2021-22	Mean	2019-20	2020-21	2021-22	Mean
Farmers Practice	25.20	21.60	13.60	20.13	9.98	9.04	11.26	10.09
Demonstration Practice	8.40	6.40	4.40	6.40	15.38	12.72	14.46	14.18
% control over FP	66.6	70.37	67.65	68.21	54.15	40.65	28.39	40.54
T value (0.05)	72.26	2.26	2.26	-	2.26	2.26	2.26	-

FP : Farmers practices

Table 3. Comparative performance of black pepper under demonstrations and farmers practice (2019-20 to 2021-22)

Year	Yield (q ha ⁻¹)		Cost of cultivation (Rs. ha ⁻¹)		Gross income (Rs. ha ⁻¹)		Net returns (Rs. ha ⁻¹)		B:C ratio	
	Demo	FP	Demo	Fp	Demo	Fp	Demo	Fp	Demo	FP
2019-20	15.38	9.98	140936	118256	492160	302720	351224	184464	3.49	2.56
2020-21	12.72	9.04	153156	127156	483360	343520	330204	216364	3.16	2.70
2021-22	14.46	11.26	158456	140456	650700	461700	492244	321244	4.11	3.29
Average	14.18	10.09	150849	128623	542073	369313	391224	240690	3.58	2.85

FP : Farmers practices

The highest technology gap of 75.25 q ha⁻¹ recorded in 2020-21, surpassing 72.62 q ha⁻¹ (2019-20) and 73.54 q ha⁻¹ (2021-22), due to variations in soil fertility status, dissimilarity in agronomic practices, adoption of technology by farmers and weather variability. Hence technologies specific to particular location are necessary to bridge these gaps (Chaitanya *et al.*, 2020). Kale *et al.* (2020) in tomato and Kumari *et al.* (2022) in *kharif* onion. Technology index varied between 82.52 % to 83.56 %, with an overall average of 83.87% (Table 4). This reflects the efficacy of the implemented technological interventions. The high index signifies robust technological feasibility and reflecting strong performance of technological intervention in foot rot management and yield enhancement through effective adoption. FLD

exhibited extension gap of 5.40 q ha⁻¹, 3.68 q ha⁻¹ and 3.20 q ha⁻¹ across 2019-20 to 2021-22, with an average of 4.09 q ha⁻¹, representing the yield differential between technology- demonstrated plots and farmers practices. This positive gap quantifies the tangible benefits of technology transfer, with demonstration plots outperforming traditional methods by 28-54% annually despite real farm variability. These interventions led to a noticeable reduction in foot rot disease incidence and higher pepper production compared to plots managed under traditional farmers practices. These findings are in conformity with earlier finding of Singh (2022) and Kumari & Singh (2023) in various other crops. Thus, emphasizing the importance of farm education using various agricultural extension methods such as FLDs.

Table 4. Yield, technology gap, extension gap and technology index of front line demonstrations during 2019-20 to 2021-22

Year	Yield (q ha ⁻¹)		Potential yield of Panniyur-1 (q ha ⁻¹)	Technology gap (q ha ⁻¹)	Extension gap (q ha ⁻¹)	Technology index (%)
	Demo	FP				
2019-20	15.38	9.98	88.00	72.62	5.40	82.52
2020-21	12.72	9.04		75.25	3.68	85.54
2021-22	14.46	11.26		73.54	3.20	83.56
Average	14.18	10.09		73.80	4.09	83.87

Conclusion

The FLD clearly revealed that the adoption of recommended practice, foliar application of pepper special [$@ 5 \text{ g L}^{-1}$ of water] during pre-flowering (fortnight of May) and post flowering period (fortnight of July), followed by soil drenching (3 litre veins⁻¹) of Arka microbial consortium $@ 20 \text{ g L}^{-1}$ in June and August, and soil drenching (3 litre veins⁻¹) of Arka Actinoplus $@ 20 \text{ g L}^{-1}$ in September proved feasible, economically viable and effective strategies for managing foot rot disease and increasing black pepper yield. These demonstrations have successfully convinced many farmers to adopt the technology due to its benefits in disease management, problem solving and enhancing decision making in farming practices.

Acknowledgements

The authors gratefully acknowledge the support extended by Karnataka Veterinary, Animal and Fisheries Sciences University, Bidar and the financial assistance provided by ICAR-ATARI, Bengaluru (Zone XI) to ICAR-KVK (D.K)

Mangaluru for effective execution of frontline demonstrations in farmers' fields. We also express our sincere thanks to ICAR-Indian Institute of Horticultural Research, Bengaluru and ICAR-Indian Institute of Spices Research, Calicut for their valuable technological contributions. Authors gratefully acknowledge the farming community for their generous cooperation in allowing us to carry out demonstrations in their fields.

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