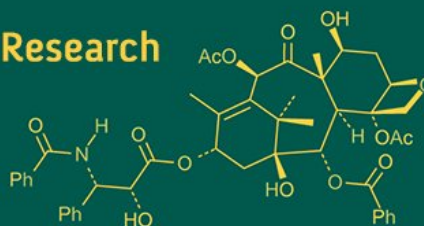


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Akurathi Ramya
Department of Plant
Pathology, Junagadh
Agricultural University,
Junagadh, Gujarat, India

Emmadi Venu
Division of Plant Pathology,
ICAR-Indian Agricultural
Research Institute, New Delhi,
India

Kelaiya DS
Principal, College of
Agriculture, Junagadh
Agricultural University,
Amreli, Gujarat, India

Bhaliya CM
Senior Scientist, ICAR-IIGR,
Junagadh, Gujarat, India

Corresponding Author:
Akurathi Ramya
Department of Plant
Pathology, Junagadh
Agricultural University,
Junagadh, Gujarat, India

Evaluation of fungicidal treatments for the management of dry root rot caused by *Macrophomina phaseolina* (TASSI) goid and their effect on disease suppression, yield enhancement and economic returns in mungbean [*Vigna radiata* (L.) Wilczek]

Akurathi Ramya, Emmadi Venu, Kelaiya DS and Bhaliya CM

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Abstract

Economic evaluation is an important criterion for identifying profitable fungicidal treatments for the management of dry root rot of mungbean caused by *Macrophomina phaseolina*. The fungicidal treatments showed considerable variation in seed yield, yield increase over the untreated control, additional income, net realization and income cost-benefit ratio (ICBR). Among the treatments, T₈, comprising seed treatment with carbendazim 50% WP followed by soil drenching with carbendazim 50% WP, proved to be the most economically viable treatment. It recorded the highest yield increase of 130.82 kg ha⁻¹ over the untreated control, resulting in maximum additional income of ₹8372.48 ha⁻¹, net realization of ₹7772.48 ha⁻¹ and ICBR of 1:13.95. Treatment T₉ ranked second with a net realization of ₹6297.68 ha⁻¹ and ICBR of 1:13.35, followed by T₁₂ with an ICBR of 1:10.65. Overall, carbendazim-based seed treatment followed by soil drenching emerged as the most profitable treatment for effective management of dry root rot while improving mungbean productivity and economic returns.

Keywords: *Macrophomina phaseolina*, dry root rot, mungbean, fungicides, economic evaluation

Introduction

Pulses are an important component of diets worldwide and constitute a major source of affordable, plant-based protein, particularly in developing countries. When consumed in combination with cereals, pulses provide a nutritionally complementary source of high-quality vegetarian protein and contribute significantly to food and nutritional security (Ali and Sen Gupta, 2012; Calles *et al.*, 2019; Venu *et al.*, 2023; Ramya *et al.*, 2026) [1, 3, 18, 17]. In recognition of their nutritional, economic and environmental importance, the United Nations General Assembly declared 2016 as the “International Year of Pulses” to promote awareness of their contribution to sustainable food systems and human nutrition (Khan, 2016; Calles *et al.*, 2019) [6, 3].

Mungbean [*Vigna radiata* (L.) Wilczek] is one of the important grain legumes cultivated extensively in Asia, particularly in India, Southeast Asia and East Asia (Lambrides and Godwin, 2017). It belongs to the family Leguminosae and is commonly known as green gram or “golden gram”, owing to the nutritional and economic value of its seeds. Mungbean is considered to have originated in the Indian subcontinent, where its domestication dates back to approximately 1500 BC (Vavilov, 1926). The crop is characterized by its short duration, relatively low input requirements and adaptability to tropical and subtropical agro-ecologies (Lawn, 1983) [11]. Although mungbean generally exhibits a short-day response, its cultivation is possible over a broad geographical range where temperatures remain above 15 °C (Imrie *et al.*, 1981) [5]. Its short growth cycle also enables its inclusion in diverse cropping systems, making it an important component of sustainable and diversified agricultural production.

Despite its adaptability and importance, mungbean production is constrained by several biotic stresses, including insect pests, weeds and plant pathogens.

Among the major diseases affecting the crop are viral diseases such as mungbean yellow vein mosaic, fungal diseases including *Cercospora* leaf spot, powdery mildew, dry root rot, web blight and anthracnose, and bacterial diseases such as bacterial blight (Khattak *et al.*, 2000; Lal, 1987; Pandey *et al.*, 2018; Roy *et al.*, 2023)^[8, 9, 14, 18]. These diseases can adversely affect plant growth, yield and seed quality, thereby limiting the productivity and profitability of mungbean cultivation. Among the fungal diseases, dry root rot has emerged as an important constraint in several mungbean-growing regions. The disease has been reported from major production areas in India, Pakistan, Uganda, China and parts of South and North America, highlighting its widespread geographical distribution and potential threat to mungbean production (Allen *et al.*, 2017)^[2].

Dry root rot (DRR) of mungbean, caused by the soil- and seed-borne necrotrophic fungus *Macrophomina phaseolina* (Tassi) Goid, is considered one of the most destructive diseases of the crop (Pandey *et al.*, 2020)^[13]. The pathogen possesses a wide host range and is capable of surviving in soil and infected plant residues for several years, primarily through the formation of persistent survival structures. Its ability to withstand unfavorable environmental conditions and infect plants at different stages of crop development makes disease management particularly challenging (Pandey *et al.*, 2021)^[15]. Under favorable conditions, the pathogen colonizes the root system and causes characteristic symptoms, including brown to black discoloration and rotting of roots, followed by progressive wilting, premature drying and, in severe cases, complete plant death (Khan *et al.*, 2017)^[7].

The development and severity of dry root rot are strongly influenced by environmental conditions. High soil and air temperatures combined with low soil moisture create favorable conditions for disease development and intensification (Saleh *et al.*, 2010)^[19]. The pathogen can spread through infested soil, plant debris and infected seed, facilitating its transmission within and between fields. Secondary spread from infected to healthy plants may occur through soil contact, while colonization of vascular tissues can facilitate movement of the pathogen within the host plant (Gupta *et al.*, 2012)^[1]. The persistence of *M. phaseolina* in soil, its broad host range and its association with warm and moisture-deficient conditions pose significant challenges for effective disease management, particularly under changing climatic conditions.

Considering the increasing importance of mungbean as a source of protein and its vulnerability to dry root rot, comprehensive investigations on the pathogen, disease development, variability and effective management strategies are essential. A better understanding of the cultural, morphological and pathogenic characteristics of *M. phaseolina*, together with evaluation of suitable chemical, biological and botanical management approaches, is necessary for developing sustainable strategies for reducing dry root rot losses in mungbean. Therefore, the present

study was undertaken to evaluate the efficacy and economic feasibility of different fungicides for managing dry root rot of mungbean, with particular emphasis on minimizing disease incidence, improving crop productivity and enhancing economic returns.

Materials and Methods

1. Field experimental conditions and experimental design

The field experiment was conducted at the Research Farm, Department of Plant Pathology, Junagadh Agricultural University (JAU), Junagadh, during the summer seasons of 2025 and 2026 to evaluate the efficacy of fungicides that showed promising activity under *in vitro* conditions against *Macrophomina phaseolina*, the causal pathogen of dry root rot of mungbean. The experiment was laid out in a Randomized Block Design (RBD) comprising 13 treatments with three replications. Mungbean variety JG-37 was used for the experiment and sown at a seed rate of 20 kg ha⁻¹ by line sowing. The gross plot size was 3.0 × 3.0 m, with a spacing of 30 × 10 cm. All recommended agronomic practices were followed uniformly throughout the crop period to ensure healthy crop growth and reliable evaluation of the treatments.

2. Preparation and application of pathogen inoculum

For artificial disease establishment, a spore suspension of the pathogen was prepared in sterile distilled water and adjusted to a concentration of 1 × 10⁶ conidia ml⁻¹. The pathogen was mass multiplied on a 9:1 sand-maize meal medium, having a population of 2 × 10⁶ CFU ml⁻¹. The pathogen-infested inoculum was incorporated into the soil at the rate of 10 g per metre row length (500 g plot⁻¹), at a depth of approximately 5 cm, one week before sowing to ensure adequate disease pressure, as suggested by Patil (2012)^[16].

3. Fungicide treatments and application methods

The fungicides selected for field evaluation were those that exhibited promising antifungal activity against *M. phaseolina* under *in vitro* conditions (Table 1). Each fungicide treatment was applied initially as a seed treatment before sowing. A second application was made at the onset of disease through soil drenching. The subsequent drenching application was given based on disease incidence and the respective treatment recommendations. An untreated control was maintained throughout the experiment for comparison.

4. Recording of disease incidence

Disease incidence was recorded at 15-day intervals after crop establishment. Observations were recorded separately for each treatment and replication by counting the number of diseased plants in relation to the total number of plants examined. The per cent disease incidence was calculated using the following formula:

$$\text{Per cent disease incidence} = \frac{\text{Number of diseased plants}}{\text{Total number of plants observed}} \times 100 \quad \text{Eq. 1}$$

5. Assessment of yield

At maturity, the crop from each plot was harvested separately and the seed yield was recorded. The yield obtained from individual plots was converted and expressed as kg ha⁻¹ for comparison among the different fungicide treatments.

6. Calculation of disease control and yield deviation

The effectiveness of the fungicide treatments was assessed based on the per cent disease control and per cent deviation in yield over the untreated control. The per cent disease control and per cent deviation in yield were calculated using the formulae suggested by Mathur *et al.* (1971)^[12].

$$\text{Disease control (\%)} = \frac{\text{P.D.I.in check} - \text{P.D.I.in treatment}}{\text{P.D.I.in check}} \times 100$$

Eq. 2

$$\text{Yield increase (\%)} = \frac{\text{Yield in treatment} - \text{Yield in check}}{\text{Yield in check}} \times 100$$

Eq. 3

Table 1: Details of fungicides for the management of dry root of mung bean under field conditions

Tr. No.	Treatments
T ₁	Seed treatment with Propineb 70 % WP
T ₂	Seed treatment with Carbendazim 50 % WP
T ₃	Seed treatment with Carboxin 37.5 % + Thiram 37.5 % WS
T ₄	T ₁ + Soil drenching with Propineb 70 % WP
T ₅	T ₁ + Soil drenching with Carbendazim 50 % WP
T ₆	T ₁ + Soil drenching with Carboxin 37.5 % + Thiram 37.5 % WS
T ₇	T ₂ + Soil drenching with Propineb 70 % WP
T ₈	T ₂ + Soil drenching with Carbendazim 50 % WP
T ₉	T ₂ + Soil drenching Carboxin 37.5 % + Thiram 37.5 % WS
T ₁₀	T ₃ + Soil drenching Propineb 70 % WP
T ₁₁	T ₃ + Soil drenching with Carbendazim 50 % WP
T ₁₂	T ₃ + Soil drenching with Carboxin 37.5 % + Thiram 37.5 % WS
T ₁₃	Control (Untreated check)

Results and Discussion

3.1 Economic evaluation of fungicidal treatments

The economic analysis of different fungicidal treatments used for the management of dry root rot of mungbean revealed considerable variation in seed yield, additional income, net realization and income cost-benefit ratio (ICBR) among the treatments (Table. 2). Economic evaluation is an important component of disease management studies because the effectiveness of a fungicide under field conditions depends not only on its ability to reduce disease severity and increase yield but also on the additional expenditure involved in its application and the economic returns obtained from the increased yield. The present investigation demonstrated that the different fungicidal treatments varied substantially in their economic performance, indicating differences in their overall profitability.

3.2 Effect of fungicidal treatments on seed yield and additional income: The increase in seed yield obtained over the untreated control directly contributed to the additional income generated by the different fungicidal treatments. The untreated control (T₁₃) recorded the lowest seed yield of 146.00 kg/ha and, consequently, no additional income was obtained over the control. In contrast, most of the fungicidal treatments resulted in appreciable increases in seed yield, thereby generating additional income.

Among all the treatments, T₈ (seed treatment with carbendazim 50% WP followed by soil drenching with carbendazim 50% WP) recorded the highest increase in yield over the untreated control, amounting to 130.82 kg/ha. The corresponding additional income was ₹8372.48/ha, which was the highest among all the treatments. The superior yield response of T₈ may be attributed to the combined effect of seed treatment and subsequent soil drenching with carbendazim, which provided protection to the crop during the early stages and reduced pathogen

activity in the rhizosphere. Reduced disease development under this treatment might have resulted in better root health, improved plant establishment and greater translocation of assimilates towards seed production.

The second highest economic response was observed with T₉ (seed treatment with carboxin 37.5% + thiram 37.5% WS followed by soil drenching with carboxin 37.5% + thiram 37.5% WS), which recorded an additional income of ₹6807.68/ha. Similarly, T₁₂ resulted in an additional income of ₹5430.40/ha, associated with a yield increase of 84.85 kg/ha over the untreated control. These results indicated that treatments capable of providing effective protection against *Macrophomina phaseolina* also contributed substantially to increased seed production and additional monetary returns.

3.3 Net realization from different fungicidal treatments

Net realization represents the economic benefit obtained after accounting for the expenditure associated with the respective fungicidal treatments. Considerable differences in net realization were observed among the treatments, indicating variation in the profitability of individual fungicide applications.

Treatment T₈ recorded the highest net realization of ₹7772.48/ha and was identified as the most profitable treatment. The higher net realization obtained with this treatment was primarily associated with its greater yield enhancement and consequently higher additional income. Despite the expenditure incurred for seed treatment and soil drenching, the substantial increase in yield resulted in a greater monetary return.

The next highest net realization was obtained with T₉, which recorded ₹6297.68/ha. This was followed by T₁₂, with a net realization of ₹4920.40/ha. These treatments also produced substantial yield advantages over the untreated control and consequently generated higher monetary returns. Among the remaining treatments, T₂ recorded a net realization of ₹3846.08/ha, followed by T₃ with ₹3270.48/ha. Treatments T₅ and T₁₀ recorded net realizations of ₹1823.04 and ₹1784.72/ha, respectively.

Relatively lower net realizations were obtained with T₁ (₹2109.20/ha), T₁₁ (₹157.76/ha) and T₆ (₹69.84/ha). The lowest net realization was recorded with T₄ (₹34.32/ha), followed by T₇ (₹46.48/ha). The low net realization under these treatments suggests that the increase in yield obtained was insufficient to compensate adequately for the expenditure associated with fungicide application.

3.4 Income cost-benefit ratio of fungicidal treatments

The income cost-benefit ratio (ICBR) provides an important measure of the economic efficiency of disease management treatments by indicating the monetary return obtained for each unit of expenditure incurred. Significant variation in ICBR was observed among the fungicidal treatments.

Treatment T₈ recorded the highest ICBR of 1:13.95, indicating that it provided the greatest economic return relative to the expenditure incurred. Thus, for every ₹1 invested in the treatment, a substantially higher return was

obtained. The high ICBR of T₈ was associated with its superior yield response and high additional income, which more than compensated for the cost of seed treatment and soil drenching.

Treatment T₉ ranked second in terms of economic efficiency, recording an ICBR of 1:13.35. Although the yield increase and additional income were lower than those obtained with T₈, the treatment still provided a highly favorable economic return. Treatment T₁₂ also demonstrated good economic feasibility, recording an ICBR of 1:10.65.

Among the moderately profitable treatments, T₂ and T₃ recorded an ICBR of 1:7.41, while T₅ and T₁₀ recorded ICBRs of 1:4.04 and 1:3.32, respectively. These treatments provided positive economic returns, although their profitability was considerably lower than that of T₈, T₉ and T₁₂.

Lower ICBRs were observed in T₁ (1:2.56), T₁₁ (1:1.26) and T₆ (1:1.14), indicating comparatively poor economic efficiency. Treatments T₄ and T₇ recorded the lowest ICBR of 1:1.03, demonstrating only marginal economic advantage over the untreated control. The comparatively poor performance of these treatments may be associated with their lower yield response and the inability of the additional yield obtained to generate substantial monetary returns.

3.5 Comparative economic performance of fungicidal treatments

When all economic parameters were considered together, considerable differences were evident in the overall performance of the fungicidal treatments. T₈ consistently ranked first, recording the highest net realization, additional income and ICBR. The treatment also resulted in the highest increase in seed yield over the untreated control. This indicates that the combined use of carbendazim 50% WP as seed treatment followed by soil drenching was not only effective in suppressing dry root rot but also economically advantageous under field conditions.

T₉ was the second most economically effective treatment, with a net realization of ₹6297.68/ha, additional income of ₹6807.68/ha and an ICBR of 1:13.35. The comparatively high economic performance of this treatment indicates that carboxin 37.5% + thiram 37.5% WS, when applied both as seed treatment and soil drenching, provided substantial economic benefits through improved crop productivity.

T₁₂ also demonstrated considerable economic potential, with a net realization of ₹4920.40/ha and an ICBR of 1:10.65. The remaining treatments showed moderate to low economic performance, depending on the magnitude of yield enhancement relative to the cost of treatment. Thus, the economic ranking of the treatments broadly corresponded with their ability to reduce disease and improve seed yield.

3.6 Economical treatment for management of dry root rot

Based on the combined consideration of additional income, net realization and ICBR, T₈ [seed treatment with carbendazim 50% WP followed by soil drenching with carbendazim 50% WP] was identified as the most economical treatment for the management of dry root rot of mungbean. It recorded the highest net realization of ₹7772.48/ha, the highest additional income of ₹8372.48/ha and the highest ICBR of 1:13.95. The treatment also produced the maximum yield increase of 130.82 kg/ha over the untreated control.

The superior economic performance of T₈ indicates that effective disease suppression can translate directly into improved crop productivity and profitability. The application of carbendazim at both the seed and soil stages may have provided prolonged protection against *M. phaseolina*, resulting in healthier plants and greater seed production. From a practical standpoint, the treatment therefore offers considerable potential for adoption by mungbean growers, particularly where dry root rot is a major production constraint.

3.7 Overall economic implications

The economic analysis clearly demonstrated that the selection of an appropriate fungicidal treatment is critical for obtaining profitable disease management. A treatment with good disease-control efficiency may not necessarily be the most economical if the cost of application is high or the corresponding increase in yield is limited. Therefore, the economic parameters considered in the present study provide a more comprehensive basis for recommending fungicides under field conditions.

Among the treatments evaluated, T₈ emerged as the most economically viable option, followed by T₉ and T₁₂. These treatments combined effective disease management with substantial yield enhancement and favorable monetary returns. In contrast, T₄ and T₇ provided only marginal economic benefits, as reflected by their very low net realization and ICBR values. The untreated control recorded the lowest seed yield of 146.00 kg/ha and did not provide any additional income.

Overall, the findings indicate that seed treatment followed by soil drenching with carbendazim 50% WP was the most profitable fungicidal strategy for managing dry root rot of mungbean under the conditions of the present investigation. The treatment offered the best combination of yield enhancement, additional income, net realization and ICBR and therefore may be considered a promising economic component of an integrated disease management strategy for dry root rot of mungbean.

Table 2: Economics of different fungicides in mungbean

Tr. No.	Quantity of fungicides required for 3 spray (kg or litre/ha)	Price of fungicides (₹/kg or litre)	Cost of treatment (₹)	Seed yield (kg/ha)	Yield increase over control (kg/ha)	Additional income (₹)	Net realization (₹)	ICBR
T ₁	2.70	500	1350	200.05	54.05	3459.20	2109.20	1 : 2.56
T ₂	1.50	400	600	215.47	69.47	4446.08	3846.08	1 : 7.41
T ₃	0.60	850	510	205.07	59.07	3780.48	3270.48	1 : 7.41
T ₄	2.70	500	1350	167.63	21.63	1384.32	34.32	1 : 1.03
T ₅	1.50	400	600	183.86	37.86	2423.04	1823.04	1 : 4.04
T ₆	0.60	850	510	155.06	9.06	579.84	69.84	1 : 1.14
T ₇	2.70	500	1350	167.82	21.82	1396.48	46.48	1 : 1.03
T ₈	1.50	400	600	276.82	130.82	8372.48	7772.48	1 : 13.95
T ₉	0.60	850	510	252.37	106.37	6807.68	6297.68	1 : 13.35
T ₁₀	2.70	500	1350	194.98	48.98	3134.72	1784.72	1 : 3.32
T ₁₁	1.50	400	600	157.84	11.84	757.76	157.76	1 : 1.26
T ₁₂	0.60	850	510	230.85	84.85	5430.40	4920.40	1 : 10.65
T ₁₃	-	0	0	146	-	-	-	-

Note: Labour charges @ 500 for 3 sprays, 300 litre of water spray/ha, Price of mungbean seed = ₹ 64/kg

Discussion

The present investigation demonstrated considerable variation in the efficacy of different fungicides against dry root rot of mungbean caused by *Macrophomina phaseolina*. Among the treatments, carbendazim-based treatments showed superior disease suppression and improvement in seed yield compared with the untreated control. The better performance of carbendazim may be attributed to its systemic nature, which enables absorption and translocation within plant tissues and provides protection against fungal infection. Its activity may help restrict pathogen development, maintain healthier root systems and improve water and nutrient uptake, thereby enhancing crop productivity.

The present findings are in close agreement with Shahid and Khan (2016) [6], who reported carbendazim as one of the most effective fungicides against *M. phaseolina* in mungbean, recording about 44 per cent reduction in root rot severity. Similarly, Suryawanshi *et al.* (2008) [22] reported 58.45 per cent disease control with carbendazim. In the present investigation, carbendazim resulted in 58.74 per cent disease reduction, which was comparable to their findings. The variation in disease control may be associated with differences in fungicide dose, application method, environmental conditions, pathogen pressure and crop growth stage.

The effectiveness of carbendazim may also be attributed to its benzimidazole mode of action, which interferes with fungal cell division and mitosis. Its systemic activity is particularly advantageous against soil-borne pathogens such as *M. phaseolina*, as it provides protection within plant tissues and helps restrict pathogen development during early infection.

Among the non-systemic fungicides, propineb also showed considerable potential for disease suppression and improvement in crop performance. These findings are supported by Sharma and Jain (2014) [21] and Patel *et al.* (2017) [24], who reported effective disease suppression with propineb. Its multisite mode of action provides broad-spectrum protective activity against fungal pathogens. However, as a predominantly protective fungicide, its effectiveness may depend on proper timing, coverage and prevailing soil and environmental conditions.

Carboxin + thiram also showed promising performance in the present study. The findings are supported by Dubey *et al.* (2011) [4] and Singh and Singh (2011) [4], who reported

that carboxin and thiram effectively reduced root rot incidence and improved crop establishment. The better performance of this combination may be attributed to the complementary activity of carboxin, which provides systemic protection, and thiram, which offers protective activity. Seed treatment with this combination can reduce initial pathogen establishment and protect seedlings during the critical stages of crop development.

The differences in disease suppression among fungicides may be attributed to their chemical nature, mode of action, systemic or protective activity, persistence and method of application. Environmental factors, particularly high temperature and low soil moisture, may also influence disease development and fungicide performance, as these conditions favour *M. phaseolina* infection.

The present study further indicated a positive relationship between disease suppression, seed yield and economic returns. Treatments providing greater disease reduction generally resulted in higher seed yield, additional income, net realization and ICBR. Carbendazim-based treatment showed particularly promising performance in terms of both disease management and economic benefits.

Overall, the present findings corroborate earlier reports on the effectiveness of carbendazim, propineb and carboxin + thiram against *M. phaseolina* and other soil-borne fungal pathogens. Among the fungicides evaluated, carbendazim exhibited superior performance and may be considered an effective and economically viable component of an integrated management strategy for dry root rot of mungbean under field conditions.

Conclusion

The present investigation clearly demonstrated that fungicidal management of dry root rot caused by *Macrophomina phaseolina* can substantially improve the productivity and economic returns of mungbean. Considerable variation was observed among the evaluated fungicidal treatments with respect to seed yield, yield enhancement over the untreated control, additional income, net realization and income cost-benefit ratio (ICBR). These variations indicated that the economic effectiveness of a fungicide depends not only on its ability to suppress disease but also on the magnitude of yield improvement obtained in relation to the cost of treatment.

Among all the treatments, T₈, comprising seed treatment with carbendazim 50% WP followed by soil drenching with

carbendazim 50% WP, emerged as the most economically viable treatment. It recorded the highest increase in seed yield over the untreated control (130.82 kg/ha), resulting in the maximum additional income of ₹8372.48/ha. The treatment also recorded the highest net realization of ₹7772.48/ha and the maximum ICBR of 1:13.95, indicating superior profitability and efficient utilization of the investment made on disease management. The consistent superiority of this treatment suggests that the combined application of carbendazim at the seed and soil stages provided effective protection against *M. phaseolina*, thereby reducing disease-associated yield losses and improving crop productivity.

T₉, involving seed treatment and soil drenching with carboxin 37.5% + thiram 37.5% WS, ranked second in economic performance, with a net realization of ₹6297.68/ha, additional income of ₹6807.68/ha and an ICBR of 1:13.35. T₁₂ also showed considerable economic potential, recording a net realization of ₹4920.40/ha and an ICBR of 1:10.65. In contrast, T₄ and T₇ provided only marginal economic advantages, as reflected by their low net realization and ICBR values.

Overall, the findings establish that carbendazim 50% WP applied as seed treatment followed by soil drenching was the most profitable fungicidal strategy under the conditions of the present investigation. Its superior combination of disease management, yield enhancement and economic returns makes it a promising component of an integrated management strategy for dry root rot of mungbean. Adoption of such economically efficient fungicidal treatments can contribute to minimizing disease-associated losses while improving the profitability and sustainability of mungbean production.

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