

RESEARCH PAPER

Potentiality of Tomato Seedling Priming through Biological Approaches for Sustainable Production

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ABSTRACT

Increasing environmental and public health concerns regarding synthetic agrochemicals have intensified the search for sustainable, eco-friendly alternatives in vegetable cultivation. A trial was conducted to evaluate the performance of biological seedling priming treatments compared with conventional chemical treatment in tomato under farmers' field conditions to evaluate the efficacy of biological priming against conventional chemical treatments on the growth, yield, and economic returns of tomato (*Solanum lycopersicum* L., cv. Himsekhar). The experiment comprised four distinct treatments: Farmers Practice (FP: No seedling treatment), Technology Option-I (TO-I: Seedling priming with Beejamrita), Technology Option-II (TO-II: Seedling priming with *Trichoderma viride*) and Technology Option-III (TO-III: Chemical treatment with Carbendazim 50WP). The results demonstrated that Carbendazim-treated seedlings produced the highest yield (62.74 t ha⁻¹) with the maximum benefit-cost ratio (1.78). Among the biological treatments, Beejamrita priming recorded significantly higher yield (56.24 t ha⁻¹) and better economic returns than *T. viride* (54.45 t ha⁻¹). The findings indicate that Beejamrita is an effective eco-friendly alternative capable of improving tomato productivity and farm profitability while minimizing chemical pesticide use. Both biological alternatives presented a robust case for suppressing fungal pathogen stress and stimulating growth, offering viable, high-return pathways for organic and low-input micro-level farming systems.

HIGHLIGHTS

- Biological seedling priming significantly improved tomato growth and productivity.
- Carbendazim produced 62.74 t ha⁻¹ yield and 1.78 B ratio.
- Beejamrita achieved 56.24 t ha⁻¹, highest among biological treatments.
- Beejamrita recorded 739.2 g fruit weight and ₹ 137,700 ha⁻¹ returns.
- *Trichoderma viride* promoted 10.5 branches and 62.4 fruits plant⁻¹.
- Beejamrita offers an eco-friendly alternative with 1.62 B ratio.

Keywords: Beejamrita bio-priming, carbendazim, sustainable production, tomato, *Trichoderma viride*

Tomato (*Solanum lycopersicum* L.) is one of the most economically important vegetable crops worldwide and serves as a major source of vitamins, minerals, dietary fiber, and health-promoting phytochemicals. The fruit is particularly rich in vitamin C, provitamin A, lycopene, β -carotene, and several antioxidant compounds that contribute to

the prevention of oxidative stress-related diseases, cardiovascular disorders, diabetes, and certain types

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of cancer (Tiwari and Choudhury, 1986; Gaied *et al.* 2013; Imran *et al.* 2020). Owing to its nutritional value and extensive industrial utilization, tomato occupies a prominent position among horticultural crops, with increasing global demand for both fresh consumption and processing.

However, intensive tomato production systems face chronic yield and quality constraints due to a high susceptibility to damping-off, root rots and early vascular wilt pathogens during the early transplanting and seedling establishment phases. Generally, farmers have relied either on intensive application of synthetic systemic fungicides or have completely omitted seedling protective measures, leading to unstable yields and low-quality produce resulting in environmental concerns, increased production costs and health hazards. Heavily relies on synthetic chemical inputs to suppress soil-borne fungal pathogens and enhance yields. However, growing public anxiety regarding the toxic residues of chemical pesticides in food chains and their degradation of soil biomass has accelerated research into eco-friendly alternatives.

Recent years have seen significant regulatory pressure from environmental scientists and heightened public awareness about toxic residues, soil microbial degradation and pathogen resistance, prompting a shift towards biological and organic crop protection methods. Plant Growth-Promoting Rhizobacteria (PGPR) and beneficial biocontrol fungi have emerged as promising components of Integrated Pest and Disease Management (IPDM). Multi-strain biological formulations like *Beejamrita* often match or exceed the performance of single-fungal isolates (such as *Trichoderma* spp.) by introducing complementary bacterial and fungal strains to the rhizosphere (Radha & Rao, 2021).

Seedling biopriming, a process that combines biological inoculation and control of seedling, has emerged as a unique physiological strategy. Beneficial microorganisms such as *Trichoderma* species, colonize root surfaces and establish physical, chemical and biochemical barriers to soil-borne plant pathogens through mycoparasitic and antibiotic actions, while synthesizing plant hormones that promote vegetative growth. At the same time, traditional fermented organic formulation such as *Beejamrita* (a microbial

preparation based on cow dung and urine rich in beneficial free-living microflora) are increasingly recognized for their dual action as biostimulants and bio-protectants which suppressing soil-borne pathogens, enhancing seedling vigor, stimulating plant growth and improving crop productivity. While chemical protectants like Carbendazim maintain an absolute edge in immediate yield returns, biological priming serves as a necessary baseline for long-term soil health and pesticide residue reduction (Sharma *et al.* 2022).

Plant Growth-Promoting Bacteria (PGPB) and beneficial biocontrol fungi present a viable route to sustainable intensification. Beneficial soil microbes colonize root zones, triggering systemic resistance, suppressing fungal pathogens and enhance nutrient uptake, induce systemic resistance and enhance plant health through multiple mechanisms.

Gopal *et al.* (2019) revealed that Biopriming of seeds and seedlings with beneficial bio-agents act as a sustainable approach for disease management and growth enhancement in solanaceous vegetables especially in tomato crops. Seedling biopriming bridges this gap by introducing active biological agents during early growth phases. Therefore, evaluating bio-priming technologies under farmers' field conditions is crucial for advancing sustainable tomato cultivation

The current trial was conducted to scientifically assess, compare and validate the effectiveness and economic feasibility of microbial priming agents like *Beejamrita* and *Trichoderma viride* against conventional fungicides such as Carbendazim 50WP as well as non-treated control plots under real farming perspectives. This study aims to address micro-level issues regarding low-quality crop yields and the prevalent lack of technical knowledge about biological formulations as alternatives among smallholder tomato farmers.

MATERIALS AND METHODS

Experimental Site

The Trials were systematically carried out across the five distinct blocks of the Coastal and saline zone of West Bengal. The performance of the premium tomato variety 'Himsekhar' was tested with four distinct technical treatments:



Operational Details of Tested Technologies

The trial evaluated four distinct technological options to address the micro-level constraint of low yield:

- ♦ **Farmers Practice (FP):** No seedling treatment.
- ♦ **Technology Option-I (TO-I):** Biological priming with *Beejamrita* (1 litre mother solution diluted in 10 Liters of water for 1 hour).
- ♦ **Technology Option-II (TO-II):** Biological priming with *Trichoderma viridae* (@ 6 g for 1 hour).
- ♦ **Technology Option-III (TO-III):** Conventional chemical treatment with Carbendazim 50WP (@ 2.5 g/l for 15 minutes).

Data Collection and Statistical Design

Agronomic growth indicators recorded included the number of effective branches per plant, number of fruits per plant and average 10-fruit weight. Economic valuations quantified the cost of cultivation, gross returns, net returns and the Benefit-Cost (B:C) ratio. Statistical variances were determined using a One-way Analysis of Variance (ANOVA) and significant variations between means were distinguished using Duncan's Multiple Range Test (DMRT) at a confidence threshold of $P < 0.05$.

RESULTS

Growth Performance

Seedling treatments significantly influenced vegetative growth. The highest number of effective branches per plant (11.8) was recorded with Carbendazim treatment, followed by *T. viride* (10.5), *Beejamrita* (9.5) and farmers' practice (7.5). Similarly, the highest number of fruits per plant (63.1) was obtained under Carbendazim treatment, while *Beejamrita* and *T. viride* also produced significantly higher fruit numbers than untreated seedlings. Fruit weight also increased significantly with seedling treatment. Carbendazim recorded the highest ten-fruit weight (860.2 g), whereas *Beejamrita* and *T. viride* produced 739.2 g and 723.4 g, respectively.

Yield Performance

Marketable fruit yield varied significantly among treatments. Carbendazim-treated seedlings produced the highest yield (62.74 t ha⁻¹) which was significantly superior to all other treatments. Among the biological treatments, *Beejamrita* priming produced a higher yield (56.24 t ha⁻¹) than *Trichoderma viride* (54.45 t ha⁻¹). The untreated control recorded the lowest yield (53.10 t ha⁻¹).

Table 1: Effects of Biological Priming and Chemical Seedling Treatments on Tomato Phenology, Yield and Economics in Tomato

Technology option	Yield component			Yield (t/ha)	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C ratio
	No. of effective branches/pl	No. of fruits/pl	10 fruit wt.					
Farmers Practice: No seedling treatment	7.5 ± 0.54 ^d	59.1 ± 0.708 ^d	708.4 ± 8.78 ^d	53.1 ± 0.792 ^b	186500.00	264800.00	78300.00	1.42 ± 0.0232 ^d
Technology Option-I: Priming the seedlings with <i>Beejamrita</i> @ 1 lit mother solution diluted with 10 lit water for 1 hr.	9.5 ± 0.719 ^b	60.1 ± 0.711 ^c	739.2 ± 9.78 ^b	56.24 ± 0.574 ^c	220400.00	358100.00	137700.00	1.62 ± 0.0164 ^b
Technology option-II: Priming the seedlings with <i>T. viride</i> @ 6 g for 1 hr.	10.5 ± 0.704 ^c	62.4 ± 0.729 ^b	723.4 ± 9.16 ^c	54.45 ± 0.417 ^d	226700.00	341200.00	114500.00	1.50 ± 0.0188 ^c
Technology option-III: Seedlings treated chemically with Carbendazim 50WP @ 2.5g/ lit for 15 min.	11.8 ± 0.707 ^a	63.1 ± 1.01 ^a	860.2 ± 12.7 ^a	62.74 ± 1.12 ^a	221200.00	394600.00	173400.00	1.78 ± 0.0141 ^a

These findings indicate that biological seedling treatments effectively suppressed fungal diseases and promoted vigorous seedling growth, leading to improved productivity.

Economic Analysis

Economic tracking revealed that although the absolute cost of cultivation increased from the Farmers Practice (₹ 186,500/ha) to the intervention groups due to specialized inputs and labour, the net financial returns scaled dramatically. Economic analysis revealed that Carbendazim treatment generated the highest gross return (₹ 394,600 ha⁻¹), net return (₹ 173,400 ha⁻¹) and benefit-cost ratio (1.78). Among the biological treatments, Beejamrita recorded better economic returns than *T. viride*. Within the biological treatments, Beejamrita (TO-I) achieved lower management costs (₹ 220,400/ha) and higher gross returns (₹ 358,100/ha, netting a premium profit of ₹ 137,700/ha and B:C ratio of 1.62, clearly surpassing the economic efficiency of *Trichoderma viride* (TO-II:- B:C of 1.50). Although the chemical treatment remained superior economically, Beejamrita emerged as the most promising biological alternative due to its higher profitability and environmentally friendly nature.

DISCUSSION

Chemical vs. Biological Treatments

The absolute dominance of Carbendazim 50WP in yield emphasizes the high baseline pressure of fungal pathoflora within the soils. As a broad-spectrum systemic benzimidazole fungicide, Carbendazim inhibits micro-tubule polymerization during fungal cell division, providing immediate, highly predictable protection to vulnerable seedling roots against damping-off (*Pythium* spp.), root rot (*Rhizoctonia solani*) and early wilt (*Fusarium oxysporum*) (Singh *et al.* 2016). This intense minimization of biological stress allowed the tomato seedlings to maximize their genetic vegetative capacity, resulting in advanced branching, uniform fruit sizing and higher productivity.

However, the biological priming options (TO-I and TO-II) demonstrated statistically robust increases in yield traits compared to the untreated control. This underscores that bio-priming provides measurable physiological benefits, acting as both an eco-friendly

surrogate or alternative of chemical fungicide and a growth biostimulant (Mishra *et al.* 2018).

Comparative Dynamics Between Beejamrita and *Trichoderma viride*

The comparison between the two biological strategies reveals distinct physiological mechanisms:

- ♦ ***Trichoderma viride*:** This treatment excelled at inducing structural vegetative branching (10.5) and increasing individual fruit numbers (62.4). *Trichoderma* spp. are known to aggressively colonize plant root tissues, producing secondary metabolites like harzianic acid and tricholin, which function as auxin-analogues to drive root branching and vegetative site proliferation (Vinale *et al.* 2014). However, the high fruit load under TO-II likely caused resource dilution, leading to a smaller individual fruit weight (723.4g of per 10 fruits).
- ♦ **Beejamrita:** Conversely, Beejamrita priming yielded significantly larger, heavier fruit (739.2g of per 10 fruits), which proved its superiority in overall yield (56.24t/ha). Beejamrita serves as a rich source of beneficial free-living bacteria, including *Azotobacter*, *Phosphobacteria* and *Pseudomonas*, alongside essential macro- and micro-nutrients derived from its organic components (Sreenivasa *et al.* 2010).

The humic and fulvic fractions present in bovine-derived organic priming agents enhance cell membrane permeability and promote steady, prolonged carbohydrate assimilation. This physiological buffering helps optimize the source-to-sink mobilization of photosynthates into developing fruit tissue. As a result, the plant produces heavier individual fruits, allowing Beejamrita to outperform *T. viride* in total marketable yield despite having fewer total fruits per plant.

The present investigation demonstrated that seedling priming significantly improved tomato growth and productivity. Carbendazim provided maximum disease protection, resulting in superior vegetative growth, fruit development and yield. However, Beejamrita performed remarkably well among biological treatments. The improvement may be attributed to beneficial microbial populations present in Beejamrita, which enhance nutrient availability, stimulate plant growth hormones,



improve root development and suppress pathogenic fungi. Similarly, *Trichoderma viride* enhanced seedling vigor and yield through antagonistic activity against soil-borne pathogens and induction of plant defense mechanisms. Although chemical treatment achieved the highest productivity, biological treatments offer environmentally safe alternatives that reduce chemical dependency while maintaining satisfactory yields.

RECOMMENDATION

Considering environmental safety, sustainability and farmer acceptability, Beejamrita @ 1 L mother solution diluted in 10 L water for one hour is recommended as the most suitable, effective biological seedling treatment for tomato cultivation where reduced chemical input is preferred. For sustainable tomato production, farmers are recommended to adopt Beejamrita seedling priming. This practice improves fruit quality and enhances economic resilience against volatile market costs. For sustainable tomato cultivation, seedling priming with Beejamrita @ 1 L mother solution diluted in 10 L water for one hour is recommended as the most suitable biological treatment. Where immediate disease control and maximum yield are the primary objectives, Carbendazim seedling treatment remains the most effective option.

GENERATIVE AI DECLARATION

The author(s) confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript, and no images were manipulated using AI. The authors developed and verified all scientific content, data analysis, interpretation of results, and conclusions. The authors take full responsibility for the accuracy, integrity, and originality of the work presented, and no AI tool was listed as an author

FEEDBACK FOR FUTURE RESEARCH

From an agro-ecological standpoint, Beejamrita demonstrates strong merit for micro-level deployment. It offers a higher B:C ratio (1.62) and a lower cost of cultivation compared to commercial *T. viride* formulations, which often require cold-chain stability and commercial manufacturing overheads.

Despite these positive outcomes, feedback from participating farmers highlighted a key constraint: a lack of standardized management and a reliable supply of premium organic ingredients, which can lead to variable quality in final yields. This indicates a clear need for future research into shelf-stable, concentrated bio-priming formulations that combine the physiological benefits of cow-derived microbial matrices with the targeted disease-suppressive capabilities of elite *Trichoderma* strains.

CONCLUSION

The Trial demonstrated that seedling priming significantly influences tomato productivity and profitability. It also revealed that while conventional chemical seedling treatment with Carbendazim 50WP provides the highest marketable yield (62.74 t ha⁻¹) and maximum economic return of tomato under high pathogen pressure whereas biological priming presents a highly viable, eco-friendly alternative. Among the organic interventions, seedling priming with Beejamrita @ 1 lit mother solution diluted with 10 lit water for 1 hr. is highly effective for micro-level agricultural systems. It successfully balances crop yield (56.24 t/ha) with low input costs, achieving a superior B:C ratio (1.62) compared to *Trichoderma viride* priming alone.

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