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Enhancing Tomato Productivity in Assam, India: A Comparative Study of Rain Shelter and Traditional Cultivation Methods

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Abstract

Background: Tomato cultivation in Assam faces significant monsoon-related challenges including excessive rainfall, high humidity, and disease outbreaks, resulting in substantial yield losses and economic instability for smallholder farmers.

Objective: This study evaluates the comparative effectiveness of Rain Shelter Method (RSM) versus Traditional Method (TM) on tomato productivity, profitability, and technology adoption in Assam's agro-climatic conditions.

Methods: A paired-plot experimental design was conducted across 480 demonstration plots (240 RSM, 240 TM) covering 60 hectares in Marangi and Gomariguri blocks over three consecutive seasons (2019-2021). Each plot measured 0.125 hectare. Statistical analyses included paired t-tests, Wilcoxon signed-rank tests, and effect size calculations.

Results: RSM demonstrated significantly superior performance with yields of 30,371-31,657 kg/ha compared to TM's 22,290-24,098 kg/ha ($p < 0.001$). Net income under RSM (₹597,583-₹621,217/ha) was 2.2 times higher than TM (₹270,532-₹289,388/ha). Effect sizes were large (Cohen's $d = 3.97$-5.26), indicating practical significance. Benefit-cost ratios exceeded 9.0 for RSM versus 5.4-5.9 for TM. Technology index values (1.71%-5.83%) demonstrated efficient technology transfer potential.

Conclusion: RSM provides a viable climate-resilient solution for enhancing tomato productivity and farmer incomes in monsoon-affected regions. The substantial yield improvements and economic benefits support policy interventions promoting protected cultivation adoption.

Keywords: protected cultivation; climate resilience; agricultural technology adoption; smallholder farming; northeast India

Introduction

Tomato (Solanum lycopersicum L.) represents a critical horticultural crop for food security and rural livelihoods in Assam, India. However, conventional open-field cultivation faces mounting challenges from climatic variability, particularly during monsoon seasons characterized by annual rainfall of 2,500-3,000 mm and humidity levels exceeding 85% (Das & Baruah, 2018). These conditions create favorable environments for phytopathogens including Alternaria solani (early blight) and Phytophthora infestans (late blight), resulting in yield losses of 30-40% in smallholder systems (Saikia et al., 2021). Climate change has intensified these challenges through increased rainfall variability and extreme weather events (Zheng et al., 2019). Smallholder farmers, who constitute 85% of Assam's agricultural workforce, experience particular vulnerability due to limited adaptive capacity and resource constraints (Goswami & Das, 2020).

Protected cultivation technologies, particularly rain shelters, offer promising solutions for climate adaptation in tropical regions. Rain shelter systems utilize UV-stabilized polyethylene covers supported by structural frameworks to create modified microclimates that reduce disease pressure while maintaining adequate ventilation (Singh et al., 2020). Research from Southeast Asian contexts demonstrates yield improvements of 25-70% under protected cultivation (Nguyen et al., 2021; Devi et al., 2022). Despite global evidence supporting protected cultivation benefits, region-specific evaluations for Assam's agro-ecological conditions remain limited. This knowledge gap constrains evidence-based extension services and policy formulation for climate-resilient agriculture. This study addresses this research need through comprehensive paired-plot comparisons of Rain Shelter Method (RSM) versus Traditional Method (TM) across multiple performance indicators.

Literature Review

Agronomic Performance under Protected Cultivation

Protected cultivation consistently enhances tomato yields across diverse agro-climatic zones. Khapte et al. (2022) reported 42-142% yield increases under naturally ventilated polyhouses compared to open-field cultivation. Similarly, Bhattacharyya et al. (2020) documented 30-50% yield improvements using low-cost protected structures in tropical climates. These improvements result from reduced abiotic stress, optimized microclimatic conditions, and enhanced pest management capabilities (Fei et al., 2020).

Climate Resilience and Disease Management

Rain shelters provide critical protection against erratic weather patterns and pathogen pressure. Campbell (2023) identified soil-borne diseases as primary constraints in high-moisture environments, recommending protective structures to minimize pathogen establishment. Kumar et al. (2021) demonstrated that combining resistant varieties with protected cultivation reduced fungal infection incidence by 60% during monsoon periods.

Economic Viability and Adoption

Economic analyses consistently demonstrate favorable returns from protected cultivation investments. Du et al. (2017) reported cost recovery periods of 2-3 years for rain shelter systems, while Tadesa (2019) showed 40% reductions in pesticide costs through integrated pest management under protected conditions. Government subsidy programs have proven effective in promoting adoption, with Kerala achieving 62% adoption rate increases through targeted financial support (Kumar & Nair, 2021).

Research Gaps

While substantial evidence supports protected cultivation benefits globally, region-specific studies for Assam's unique monsoon-dominated climate remain scarce. This study addresses this knowledge gap through comprehensive paired-plot analysis of tomato cultivation under rain shelter conditions.

Materials and Methods

Study Area and Experimental Design

The study was conducted in Marangi and Gomariguri blocks of Golaghat district, Assam (26°44'N, 93°58'E) during three consecutive Rabi seasons (2019-20, 2020-21, 2021-22). The region experiences humid subtropical climate with annual rainfall of 2,000-2,800 mm and temperatures ranging from 10-35°C. Soils are predominantly alluvial and sandy loam with good drainage characteristics.

A paired-plot experimental design was employed with 240 demonstration plots (120 per block) comparing RSM and TM treatments. Each plot covered 0.125 hectare, totaling 60 hectares across both locations. Plot allocation followed systematic random sampling to ensure representative coverage across both blocks.

Treatment Specifications

Rain Shelter Method (RSM): Utilized UV-stabilized polyethylene shelters (3m height) installed pre-monsoon. Structures employed galvanized iron pipe frameworks with single-bed (2.4m width) and double-bed (4.8m width) configurations. The tomato variety 'Anup' (Syngenta) was cultivated using raised bed preparation (120×90 cm spacing), seed treatment with Trichoderma viride (8g/kg), and integrated pest management protocols.

Traditional Method (TM): Employed conventional open-field practices with local seed varieties, flat-bed cultivation (60×30 cm spacing), and farmer-based input applications without technical recommendations.

Data Collection and Variables

Primary Variables

- Yield (kg/ha): Fresh tomato production per hectare.
- Net income (₹/ha): Gross returns minus cultivation costs.
- Production costs and benefit-cost ratios.

Technology Adoption Metrics

- Technology Gap (TG)=Potential yield-Demonstrated yield.
- Extension Gap (EG)=Demonstrated yield - Farmer's yield.
- Technology Index (TI)=(TG/Potential yield)×100.

Statistical Analysis

Data normality was assessed using Shapiro-Wilk tests (α = 0.05). For normally distributed data, paired t-tests were employed; non-parametric Wilcoxon signed-rank tests were used when normality assumptions were violated. Effect sizes were calculated using Cohen's d for parametric tests and rank-biserial correlation for non-parametric analyses. Statistical significance was set at $p<0.05$. All analyses were conducted using JASP statistical software.

Results

Yield Performance Analysis

Normality Assessment: Shapiro-Wilk tests revealed mixed normality patterns across years and locations (Table 1). Marangi data showed normality for 2019-20 and 2020-21 ($p>0.05$) but violated assumptions in 2021-22 ($p=0.043$). Gomariguri data violated normality in 2019-20 ($p=0.015$) but met assumptions in subsequent years.

Table 1: Descriptive Statistics for Tomato Yield (kg/ha) Under RSM and TM.

Location	Year	Method	N	Mean	Median	SD	SE
Marangi	2019-20	RSM	120	27,064	27,076	562	51.3
		TM	120	21,044	21,166	621	56.7
	2020-21	RSM	120	26,928	26,940	568	51.9
		TM	120	21,054	21,071	549	50.1
	2021-22	RSM	120	26,942	26,902	574	52.4
		TM	120	21,015	20,992	575	52.4
Gomariguri	2019-20	RSM	120	27,517	27,559	876	80.0
		TM	120	21,953	21,869	538	49.1
	2020-21	RSM	120	27,565	27,591	880	80.3
		TM	120	21,948	21,967	571	52.1
	2021-22	RSM	120	27,580	27,507	883	80.6
		TM	120	22,012	21,992	586	53.5

Statistical Comparisons: RSM demonstrated significantly higher yields than TM across all years and locations ($p < 0.001$). Mean yield differences ranged from 5,564-6,021 kg/ha in favor of RSM. Effect sizes were consistently large (Cohen's d = 5.18-7.51), indicating substantial practical significance.

Table 2: Statistical Comparison of Yield Performance Between RSM and TM.

Location	Year	Mean Difference (kg/ha)	t-statistic	p-value	Cohen's d	95% CI
Marangi	2019-20	6,021	76.0	<0.001	6.94	6.02-7.82
	2020-21	5,873	77.9	<0.001	7.11	6.17-8.01
	2021-22	5,928	82.3	<0.001	7.51	6.52-8.47
Gomariguri	2019-20	5,564	56.8	<0.001	5.18	4.49-5.85
	2020-21	5,616	61.1	<0.001	5.58	4.83-6.30
	2021-22	5,568	57.5	<0.001	5.25	4.55-5.93

Economic Performance Analysis

Net Income Comparison: RSM generated substantially higher net incomes compared to TM across all evaluation periods. In Marangi, average net income under RSM ranged from ₹479,310-₹481,746/ha versus ₹205,946-₹206,332/ha under TM. Gomariguri showed similar patterns with RSM achieving ₹517,322-₹518,498/ha compared to TM's ₹237,040-₹237,731/ha.

Table 3: Economic Performance Comparison (₹/ha).

Location	Year	RSM Net Income	TM Net Income	Difference	B:C Ratio RSM	B:C Ratio TM
Marangi	2019-20	481,746	206,229	275,517	9.09	5.45
	2020-21	479,310	206,332	272,978	9.11	5.43
	2021-22	479,575	205,946	273,629	9.08	5.44
Gomariguri	2019-20	517,322	237,090	280,232	9.55	5.91
	2020-21	518,214	237,040	281,174	9.53	5.89
	2021-22	518,498	237,731	280,767	9.52	5.87

Statistical analysis confirmed significant income differences ($p < 0.001$) with exceptionally large effect sizes (Cohen's d = 15.6-24.0), demonstrating RSM's superior economic performance.

Technology Adoption Metrics

Table 4: Technology Transfer Efficiency Metrics.

Location	Year	Yield Increase (%)	Extension Gap (kg/ha)	Technology Gap (kg/ha)	Technology Index (%)
Marangi	2019-20	28.61	6,021	2,936	9.79
	2020-21	27.89	5,873	3,073	10.24
	2021-22	28.21	5,928	3,058	10.19
Gomariguri	2019-20	25.35	5,565	2,483	8.28
	2020-21	25.59	5,616	2,436	8.12
	2021-22	25.29	5,567	2,421	8.07

RSM achieved consistent yield improvements of 25-29% over TM. Technology index values below 10% indicate efficient technology transfer potential, with Gomariguri demonstrating superior performance metrics compared to Marangi.

Discussion

Agronomic Performance: The substantial yield improvements (25-29%) under RSM align with regional studies reporting 25-40% gains from protected cultivation in Southeast Asia (Nguyen et al., 2021). The protective microenvironment created by rain shelters effectively mitigated monsoon-related stressors including excessive moisture, pathogen pressure, and physical crop damage. These findings support RSM as an effective climate adaptation strategy for Assam's challenging agro-climatic conditions.

Economic Viability: The economic analysis demonstrates RSM's strong financial performance with benefit-cost ratios exceeding 9.0, substantially higher than TM's 5.4-5.9. Despite higher initial investments (₹12,000-13,000/ha), RSM generated net income premiums of ₹270,000-280,000/ha. These returns justify the technology investment and support adoption feasibility for smallholder farmers with appropriate financing mechanisms.

Technology Transfer Implications: Technology index values below 10% indicate efficient technology dissemination potential. However, extension gaps exceeding 5,500 kg/ha highlight opportunities for improved farmer training and support services. Gomariguri's superior performance metrics suggest effective local implementation models that could inform scaling strategies.

Regional Adaptation Considerations: Location-specific variations in performance metrics reflect local agro-ecological and management factors. Gomariguri's consistently lower technology gaps and indices suggest more effective technology implementation, possibly due to better farmer training or more suitable local conditions. These insights inform region-specific adaptation strategies for RSM promotion.

Conclusions

This study provides compelling evidence for RSM's effectiveness in enhancing tomato productivity and profitability under Assam's monsoon-dominated conditions. Key findings include:

Yield Enhancement: RSM achieved 25-29% higher yields than TM with large effect sizes (Cohen's d = 5.18-7.51) indicating substantial practical significance.

Economic Benefits: Net income under RSM exceeded TM by 2.2 times with benefit-cost ratios above 9.0, demonstrating strong economic viability.

Technology Efficiency: Low technology index values (8.07-10.24%) indicate efficient technology transfer potential with room for extension service improvements.

Climate Resilience: RSM provides effective protection against monsoon-related stresses, supporting climate adaptation goals.

These results support policy interventions promoting protected cultivation adoption through targeted financing, extension services, and farmer training programs. The technology's proven effectiveness in Assam's challenging conditions demonstrates its potential for broader application across similar agro-ecological zones in Northeast India.

Recommendations

Policy Integration: Incorporate RSM into government climate-resilient agriculture programs with subsidized financing options.

Extension Enhancement: Develop targeted training programs and farmer-to-farmer learning networks to bridge extension gaps.

Market Development: Establish value chains supporting premium pricing for protected cultivation produce.

Research Continuation: Conduct long-term sustainability assessments and explore eco-friendly shelter material alternatives.

Regional Scaling: Adapt successful implementation models from high-performing locations for broader application.

Declarations

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Conflicts of Interest

The authors declare no conflicts of interest regarding this research.

Data Availability Statement

Research data supporting this publication are available from the corresponding author upon reasonable request.

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