



ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2026): 4.97
IJAFS 2026; 8(2): 213-221
www.agriculturaljournals.com
Received: 03-12-2025
Accepted: 04-01-2026

Ikram Alam
UG Scholar, Department of
Horticulture, Naini Agriculture
Institute (NAI), SHUATS,
Prayagraj, Uttar Pradesh,
India

Samir Ebson Topno
Assistant Professor,
Department of Horticulture,
Naini Agriculture Institute
(NAI), SHUATS, Prayagraj,
Uttar Pradesh, India

Sonal Shikha
UG Scholar, Department of
Horticulture, Naini Agriculture
Institute (NAI), SHUATS,
Prayagraj, Uttar Pradesh,
India

Corresponding Author:
Ikram Alam
UG Scholar, Department of
Horticulture, Naini Agriculture
Institute (NAI), SHUATS,
Prayagraj, Uttar Pradesh,
India

Adoption of modern bottle gourd cultivation technologies: A review with field-level evidence from East Champaran, Bihar

Ikram Alam, Samir Ebson Topno and Sonal Shikha

DOI: <https://www.doi.org/10.33545/2664844X.2026.v8.i2c.1187>

Abstract

A Bottle gourd (*Lagenaria siceraria*) is an important vegetable crop of the cucurbit family that is widely grown in eastern India, valued for its adaptability, nutritional benefits, and consistent market demand. The productivity of bottle gourd in Bihar remains below its full potential, despite favourable conditions for such a crop, mainly because only a limited number of modern cultivation techniques are being adopted. This study provides a comprehensive review of modern practices for growing bottle gourd and includes field-level evidence from the East Champaran district of Bihar. The review combines findings from various scientific publications (Singh & Maurya, 2019; Choudhary & Sharma, 2021; Patel & Rajput, 2018; Kumar *et al.*, 2021), reports from ICAR and KVK, government releases, as well as primary data collected through a formal survey of 949 farmers across seven blocks. The adoption of key technologies, including hybrid varieties, mulching, integrated nutrient management, trellising, drip irrigation, and integrated pest management, was thoroughly assessed. The field survey results showed significant variation in adoption rates across different blocks, with Raxaul having the highest percentage of bottle gourd farmers (81.8%). In comparison, Adapur (25.0%) and Motihari (32.2%) showed lower levels of adoption. The reviewed studies generally reported a yield increase of 20-35% and improved benefit-cost ratios with modern cultivation practices compared to traditional methods. However, high initial costs, limited technical knowledge, and inadequate access to quality inputs have been identified as major barriers to adopting these technologies. The review emphasizes the need for a multidisciplinary extension approach, location-specific interventions, and policy incentives to promote the sustainable adoption of modern technologies for bottle gourd cultivation in eastern India.

Significance of the review

This review is significant because it merges research findings on bottle gourd cultivation technology with field observations from East Champaran, Bihar. The paper highlights the relationship between experimental studies and the practices adopted by farmers in the field, providing valuable insights for researchers, extension workers, and policymakers. Additionally, the study addresses the challenges and opportunities associated with each technology, specifically in terms of enhancing sustainable vegetable production in eastern India.

Keywords: Bottle gourd, modern cultivation, hybrid seeds, drip irrigation, mulching, INM, IPM, technology adoption

Introduction

India is one of the leading producers of cucurbit vegetables, and bottle gourd occupies a significant share of the vegetable area in the Indo-Gangetic plains. In eastern states such as Bihar, the crop is cultivated across multiple seasons under irrigated and rainfed conditions, providing regular cash income to farmers (Government of Bihar, 2023; Singh & Mishra, 2022) ^[18]. Despite favorable soil and climatic conditions, the average productivity of bottle gourd in many districts of Bihar remains below the attainable yield observed in research stations and progressive farmer fields. This gap is largely attributed to the incomplete adoption of modern production technologies, sub-optimal input management, and limited access to quality planting material and advisory services. Over the past decade, several improved technologies have been developed and promoted for enhancing bottle gourd productivity and profitability.

These include high-yielding hybrids, drip irrigation and fertigation, plastic mulching, integrated nutrient management (INM), trellising systems, and integrated pest management (IPM) (Patel & Rajput, 2018; Prasad *et al.*, 2020; Meena *et al.*, 2021)^[11, 12, 8]. Experimental and on-farm studies have demonstrated that these interventions can increase yield by 20-35%, improve resource-use efficiency, and enhance fruit quality and market value (Singh & Yadav, 2020; Kumar *et al.*, 2021)^[17, 6]. However, adoption at the farmer level is often uneven and influenced by socio-economic conditions, awareness levels, risk perception, input availability, and institutional support.

In Bihar, particularly in vegetable-growing belts like East Champaran, bottle gourd cultivation is predominantly practiced by smallholders under resource-constrained conditions. Farmers frequently rely on traditional varieties, flood irrigation, imbalanced fertilization, and chemical-intensive pest control methods, which limit productivity and sustainability. At the same time, extension agencies such as Krishi Vigyan Kendras (KVKs), ATMA, and state horticulture departments are promoting modern practices through demonstrations and training programs, creating a dynamic transition phase in production systems (KVK Motihari, 2023; Sharma *et al.*, 2022)^[7, 14]. Although individual technologies have been studied in isolation, there is limited synthesized evidence linking scientific findings with field-level adoption patterns in specific districts. Understanding how and why farmers adopt (or do not adopt) modern practices is essential for designing targeted extension strategies and policy interventions. A location-specific review that integrates research evidence with ground-level observations can help bridge the gap between technology generation and technology utilization.

Therefore, this review aims to synthesize available scientific literature on modern bottle gourd cultivation technologies and relate it to field-level adoption trends in East Champaran district of Bihar. By examining technological performance, adoption patterns, constraints, and opportunities, the study seeks to provide practical insights for researchers, extension workers, and policymakers working toward sustainable intensification of vegetable production in eastern India.

Objectives of the study

- To study the level of acceptance of modern cultivation technology in bottle gourd farming in East Champaran.
- To determine the relative efficacy of recent versus older practices.
- To identify factors (socio-economic, infrastructure-related, and knowledge-related) influencing adoption.
- Recommend plans to achieve better adoption and increased productivity.

Study methodology

Data sources and analytical approach

This review synthesizes secondary information from ICAR institutes, KVK Motihari annual reports, ATMA publications, and peer-reviewed scientific journals, complemented by field observations from bottle gourd growing clusters. To assess technology performance and adoption trends, we employed both quantitative and qualitative tools, including adoption indices, cost-benefit analysis, and SWOT analysis, supported by descriptive statistics and comparative trend data analysis.

Search strategy and inclusion criteria

Timeframe and geographic scope: Literature and reports published between 2015 and 2024 were considered, with a geographic focus on the eastern Indo-Gangetic plains.

Source types: Eligible sources comprised peer-reviewed journal articles, ICAR and other government publications, KVK annual and technical reports, and ATMA documents. Unpublished opinion pieces and non-empirical commentaries were excluded.

Crop focus: Studies addressing bottle gourd and closely related cucurbit crops were prioritized to ensure relevance to agronomic practices and technology transfer in the target region.

Study design and outcomes: We included empirical studies and reports that presented measurable outcomes on at least one of the following: yield, farm-level economics (costs, returns, profitability), or resource-use efficiency (water, nutrients, labor). Accepted study designs included field experiments, on-farm demonstrations, farmer surveys, and economic assessments. Reviews and conceptual papers were used only for contextual background, not for quantitative synthesis.

Quality and relevance screening: Each item was screened for methodological transparency, sample size, and clarity of reported metrics. Only studies with sufficient methodological detail and quantifiable results were retained for analysis.

Synthesis approach: Selected studies were analyzed using adoption indices and cost-benefit comparisons to quantify their performance and economic viability. Additionally, SWOT analysis and field observations were utilized to interpret the barriers to adoption and the factors that enable it.

Study area description

Location and physiography East Champaran district lies between 26°16'-27°01' N latitude and 84°30'-85°16' E longitude, occupying a portion of the eastern Indo-Gangetic plains. The landscape is predominantly flat with gentle relief and extensive alluvial deposits derived from Himalayan and local fluvial processes. These conditions create a highly productive agricultural plain with good accessibility to local markets and extension services.

Climate The district experiences a subtropical monsoon climate with an annual rainfall of about 1,000-1,242 mm, most of which occurs during the June-September southwest monsoon. Seasonal temperatures range from approximately 9 °C in winter to 42 °C in summer, producing distinct *rabi* and *kharif* growing seasons and occasional heat or cold stress events that influence crop choice and management.

Soils and land use Soils are predominantly alluvial, varying from sandy loam to clay loam, with generally good natural drainage in some tracts and water-retentive heavier soils in others. Fertility is moderate to high in many areas but shows spatial variability in organic matter and micronutrients, which affects fertilizer response and crop performance. Landholdings are a mix of small and marginal farms interspersed with larger holdings, and land use is intensively cropped throughout the year.

Cropping pattern and irrigation. High cropping intensity is characteristic of the district, driven by multi-cropping systems and widespread use of perennial and supplemental irrigation (tube wells, canals, and pumps). Major crops include rice, wheat, maize, pulses, and vegetables; farmers

commonly follow cereal-vegetable or cereal-pulse rotations to maximize land use and income.

Bottle gourd cultivation. Bottle gourd is widely cultivated across most blocks, with particularly dense production in Raxaul, Ghorashan, Kesaria, Areraj, Adapur, Chhauradano, and Sangrampur. Cultivation occurs in both *kharif* and *rabi*

seasons, depending on water availability and market demand. Local production is characterized by smallholder plots, a mix of traditional and improved varieties, and variable adoption of recommended agronomic practices, making these clusters suitable for on-farm trials and technology transfer interventions.

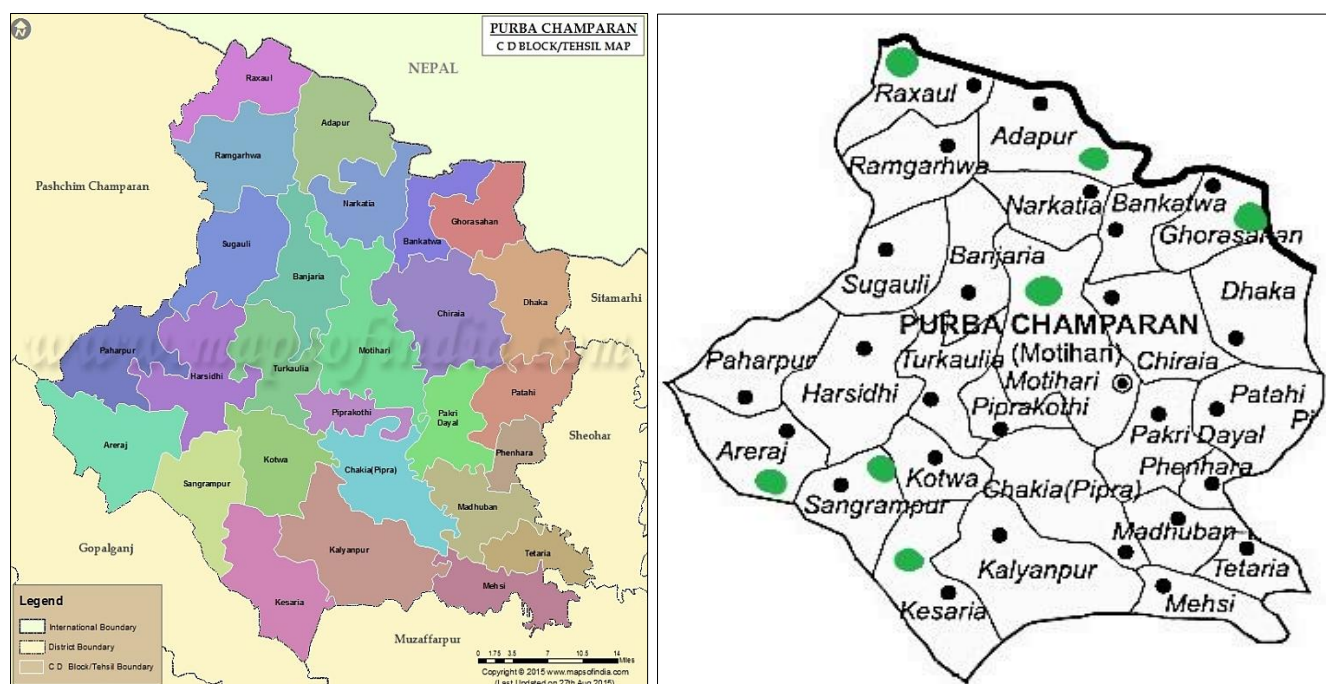


Fig 1: Location map of East Champaran district, Bihar, India, green dots on the map indicate the major bottle gourd growing blocks.

Review of modern cultivation technologies

This section synthesizes evidence from field observations, KVK demonstrations, ICAR reports, and peer-reviewed studies to evaluate contemporary technologies for bottle gourd production in East Champaran. Each subsection summarizes performance, adoption status, key benefits, constraints, and practical recommendations for scaling.

Hybrid and improved varieties

Hybrid cultivars such as Pusa Hybrid-3, Arka Bahar, Punjab Long, and Anmol LGH have consistently delivered superior performance in trials and on-farm demonstrations, showing earliness, uniform fruit shape and colour, higher fruit set, and 20-30% greater yield potential (Singh & Maurya, 2019; Choudhary & Sharma, 2021) [15, 1]. In East Champaran, hybrid seed adoption is widespread because hybrids give immediate, visible yield and marketability benefits.

Key advantages

- Higher fruit set and uniformity; improved packability.
- Early maturity, enabling better market timing.
- 20-30% yield advantage over local varieties.
- Stronger market preference and price realization.

Constraints and recommendations

- Seed cost and availability can limit uptake among marginal farmers; promote bulk procurement through FPOs and subsidized seed schemes.
- Encourage on-farm demonstrations and side-by-side comparisons to build farmer confidence in hybrid performance.

Drip irrigation and fertigation

Drip systems with fertigation have shown large efficiency gains, improving water-use efficiency by 40-60% and fertilizer-use efficiency by 30-40% in experimental and on-farm studies (Patel & Rajput 2018; Narayan *et al.* 2022) [11]. By delivering water and nutrients directly to the root zone, drip fertigation reduces evaporation and runoff while enabling precise nutrient scheduling.

Benefits

- Substantial water and nutrient savings; improved crop uniformity.
- Higher yields and quality when combined with split nutrient applications.

Barriers and recommendations

- High initial investment and limited access to micro-irrigation service providers.
- Promote micro-credit, government subsidy schemes, and village-level service providers; provide training on fertigation scheduling and maintenance.

Plastic mulching

Black polyethylene mulch consistently provides soil warming, weed suppression, moisture conservation, and has been associated with 15-20% yield increases in multiple studies (Singh & Yadav, 2020; Mohapatra & Behera, 2021) [16, 17]. In East Champaran, adoption is growing among market-oriented growers but remains uneven due to cost and disposal concerns.

Practical notes

- Use mulch with drip irrigation to maximize water and nutrient efficiency.
- Explore biodegradable mulches or organized plastic collection to reduce environmental impact.

Integrated Nutrient Management (INM)

Combining organic inputs (FYM, compost, vermicompost), chemical fertilizers, and biofertilizers improves soil health, nutrient balance, and fruit quality (Prasad *et al.* 2020; Chatterjee 2018) ^[12]. INM supports sustained productivity and reduces dependency on high fertilizer doses.

Advantages

- Improved soil structure and long-term fertility; better fruit firmness and storage life.
- Enhanced nutrient-use efficiency when integrated with fertigation.

Adoption tips

- Promote simple nutrient calendars and demonstration plots showing cost-benefit of partial organic substitution.
- Facilitate access to quality compost and biofertilizers through KVKs and FPOs.

Trellising systems

Trellising keeps vines vertical, improves light interception and airflow, reduces fruit rot, and eases harvesting. Adoption in East Champaran is moderate, mainly among progressive farmers who can absorb the labour and material costs.

Benefits

- Improved fruit quality and reduced post-harvest losses; easier crop management.

Scaling suggestions

- Promote low-cost trellis designs and community tool banks; include trellising in FLDs to demonstrate returns.

Integrated Pest Management (IPM)

IPM tools pheromone traps, neem-based sprays, and microbial biopesticides show effective pest suppression with lower chemical use (Meena *et al.* 2021) ^[8]. However, adoption remains low due to limited access to bioagents and weak pest-monitoring skills.

Barriers and actions

- Strengthen supply chains for bioagents and train farmers in pest scouting and threshold-based interventions.
- Use KVKs and farmer field schools to demonstrate IPM cost savings and safety benefits.

Knowledge level and farmer perception

Adoption decisions are strongly influenced by perceived risk and immediacy of benefits. Practices with instant, visible gains (Hybrids, mulching) spread faster, while technologies perceived as complex or risky (drip fertigation, IPM) have slower uptake. In East Champaran, knowledge gaps and fear of crop failure are major psychological barriers.

Recommendations

- Prioritize hands-on demonstrations, farmer-to-farmer learning, and short training modules that reduce perceived complexity.
- Use local success stories and cost-benefit evidence to shift perceptions.

Climate-smart practices

Climate variability, extreme heat, erratic rainfall, and occasional waterlogging threaten vegetable production. Raised beds combined with mulching and micro-irrigation improve drainage, root aeration, and moisture retention; studies report that CSA practices can protect 15-20% of area from total crop failure under extreme events (Kumar *et al.* 2021) ^[6]. Short-duration hybrids and weather-based advisories further reduce risk.

Action points

- Integrate raised beds, mulch, and micro-irrigation in extension packages.
- Strengthen KVK-led weather advisories and promote short-duration hybrids aligned with local agro-climatic windows.

Mechanization and small farm tools

Large-scale mechanization is limited in vegetables, but small, affordable tools (hand weeders, battery sprayers, low-cost trellises) reduce labour and improve timeliness. Evidence suggests 20-30% reductions in labour for weeding and plant protection with simple mechanization (Singh *et al.* 2020) ^[5].

Scaling measures

- Establish village-level custom hiring centers and agri-service providers.
- Promote battery-operated sprayers and manual mulch-laying tools through subsidies and demonstrations.

Quality improvement and post-harvest management

Modern agronomic practices improve fruit uniformity, surface quality, and reduce pest damage. Balanced fertigation and INM enhance firmness and shelf life. Studies indicate 10-15% reduction in post-harvest losses when fruits are harvested at correct maturity and handled properly (Rai *et al.* 2019) ^[13].

Priority interventions

- Train farmers on grading, shade storage, and use of ventilated crates.
- Promote market-linked aggregation and simple cold-chain options to capture higher prices without large capital outlay.

Extension services and institutional support

KVKs, ATMA, and state horticulture departments have been pivotal in disseminating hybrids, mulching, and INM. KVK Motihari frontline demonstrations report 25-30% yield gains from improved practices (Sharma *et al.* 2022) ^[14]. Yet extension reach remains limited.

Recommendations for strengthening adoption

- Expand FLDs, farmer field schools, and exposure visits; integrate digital advisories and mobile-based alerts.

- Support FPOs and youth-led agri-service enterprises to improve input access, mechanization services, and market linkages.
- Monitor and evaluate adoption through simple indicators (adoption index, cost-benefit ratios) to refine extension messages.

Synthesis and priority actions

- **High-impact, near-term:** scale hybrids, mulching, and INM through FLDs and seed/input aggregation.
- **Medium-term:** expand drip fertigation and small-scale mechanization via subsidies, micro-finance, and service providers.
- **Cross-cutting:** strengthening IPM supply chains, climate-smart advisories, and post-harvest training to convert yield gains into higher net returns.

Targeted actions supported by evidence and institutional backing can enhance the adoption of modern bottle gourd cultivation technologies in East Champaran, while also improving resilience, profitability, and sustainability.

Results and Discussion

Summary of adoption patterns: Adoption of modern bottle gourd technologies varied markedly across blocks in East Champaran. Raxaul recorded the highest commercial orientation and technology uptake, while Adapur showed the lowest adoption. These spatial differences reflect heterogeneity in market linkages, input access, irrigation, extension support, and farmer awareness.

Table 1: Adoption by block

Block	Adoption rate (%)
Raxaul	81.8
Kesaria	49.6
Sangrampur	47.8
Ghorashahan	39.7
Areraj	34.4
Motihari	32.2
Adapur	25.0

Source: Primary data collected through field survey, 2025.

Spatial and socio-economic interpretation

The exceptionally high adoption in Raxaul suggests strong market orientation and better access to quality inputs and services. Mid-range adoption in Kesaria and Sangrampur likely reflects partial access to irrigation and extension, combined with moderate market opportunities. Low

adoption in Adapur, Motihari, and Areraj points to constraints such as limited irrigation, poor seed and input supply, weaker extension outreach, and lower farmer awareness or risk tolerance.

Key drivers of variation

- **Market access and commercialization:** Blocks with closer market linkages show higher adoption because farmers capture price premiums for uniform, early maturing hybrids.
- **Input availability and affordability:** Ready availability of hybrid seed, mulching material, and micro-irrigation components correlates with higher uptake.
- **Irrigation infrastructure:** Areas with reliable irrigation are more likely to adopt water-sensitive technologies such as drip fertigation and short-duration hybrids.
- **Extension and demonstration:** Presence of active extension agents, KVK demonstrations, and farmer field schools increases farmer confidence and accelerates adoption.
- **Farmer knowledge and perception of risk:** Farmers prefer technologies with immediate, visible benefits; practices perceived as complex or risky show slower adoption.

Implications for scaling and policy

- **Targeted interventions:** Prioritize Raxaul-type clusters for scaling market-linked technologies while designing tailored support for low-adoption blocks (Adapur, Motihari, Areraj).
- **Input and service aggregation:** Facilitate seed and input aggregation through FPOs and village-level agri-service centers to reduce costs and improve access.
- **Extension intensification:** Expand frontline demonstrations, farmer field schools, and peer-learning visits in low-adoption blocks to reduce perceived risk and build skills.
- **Irrigation and finance support:** Promote subsidized micro-irrigation, micro-credit, and custom hiring services to lower entry barriers for drip fertigation and mechanization.
- **Monitoring and evaluation:** Use simple adoption indices and periodic surveys to track progress and refine interventions.

Adoption Status

Table 2: Adoption level of major modern bottle gourd cultivation technologies for adoption, and recommended action

Technology	Adoption level	Key reasons	Recommended actions
Hybrid seeds	High (65-70%)	Easy access; immediate, visible yield and market benefits	Strengthen seed supply through FPO bulk purchases and FLDs
Mulching	Moderate (35-40%)	Affordable; good awareness of benefits	Promote combined mulch + drip packages and biodegradable options
Integrated Nutrient Management	Moderate (45-50%)	Recognised soil-health and quality benefits	Provide nutrient calendars and access to quality compost/biofertilizers
Trellising	Moderate (40-45%)	Low material cost; clear quality gains	Demonstrate low-cost trellis designs and group procurement
Drip irrigation and fertigation	Low (15-20%)	High upfront cost; limited service providers	Facilitate subsidies, micro-credit, and village-level installation services
Integrated Pest Management	Low (20-25%)	Limited knowledge; weak supply chain for bioagents	Build IPM supply chains and train farmers in pest monitoring

Impact on yield

- **Traditional practice:** 180-220 q/ha.
- **Modern practice (hybrids, mulching, drip fertigation, and INM):** 240-310 q/ha.
- **Estimated yield improvement:** 20-35% depending on technology combination and management intensity.
- **Interpretation:** Combining hybrid seeds, mulching, and targeted fertigation produced the largest and most consistent yield gains in trials and demonstrations; incremental benefits accrue when INM and trellising are added.

Economic benefits

- **Net return increase:** ₹30,000-45,000 per ha under modern practices compared with traditional systems.
- **Benefit-cost ratio:** Improved from ~1.8 (traditional) to 2.4-2.6 (modern).
- **Labour and cost effects:** Mulching and trellising help reduce weeding and handling time, leading to labor savings and improved harvest efficiency. Initial investments in seed, mulch, and drip irrigation are typically recovered within one to two seasons, especially where market access is good.
- **Recommendation:** Present simple enterprise budgets and payback calculations in extension materials to help farmers evaluate investment decisions.

Factors influencing adoption

- **Farm size and household income:** Larger or better-off farms adopt capital-intensive options more readily.
- **Access to credit and subsidies:** Availability of finance and government support lowers entry barriers for drip and other investments.
- **Availability and quality of inputs:** Reliable supply of hybrid seed, mulch, biofertilizers, and drip components is critical.
- **Perceived complexity and risk:** Technologies perceived as complex or risky (drip, IPM) have slower uptake.
- **Extension support and training:** Regular demonstrations, hands-on training, and farmer-to-farmer learning accelerate adoption.
- **Market linkages:** Proximity to markets and price incentives for uniform, early produce increase willingness to invest.

Practical recommendations

- **Short term:** Scale hybrids, mulching, and INM through FLDs and seed/input aggregation to capture quick gains.
- **Medium term:** Expand access to micro-irrigation via subsidies, micro-finance, and village service providers; strengthen IPM supply chains.
- **Cross-cutting:** Provide clear, farm-level enterprise budgets, hands-on training, and peer demonstrations to reduce perceived risk and show payback timelines.

These improvements clarify adoption patterns, quantify agronomic and economic impacts, and translate findings into actionable steps for extension agents, policymakers, and farmer groups

Results and Discussion

Table 3: Distribution of Bottle Gourd Growers and Survey Coverage across Selected Blocks of East Champaran, Bihar

Block	Bottle gourd growing farmers	Total farmers surveyed	Percentage (%)
Motihari	29	90	32.2
Raxaul	90	110	81.8
Areraj	55	160	34.4
Kesaria	67	135	49.6
Adapur	35	140	25.0
Ghorashahan	95	239	39.7
Sangrampur	55	115	47.8

Key Constraints

Financial barriers

- High upfront cost of micro-irrigation (drip kits, filters, pumps) prevents many smallholders from investing despite long-term returns.
- **Mitigation:** promote phased installation, group purchases through FPOs, micro-credit, and government subsidy schemes to lower entry costs.

Input availability and quality

- Irregular supply of certified hybrid seed and bioinputs (biofertilizers, biopesticides) limits consistent adoption and undermines farmer confidence.
- **Mitigation:** strengthen local input supply chains, encourage bulk procurement by producer groups, and support local seed dealers with quality assurance training.

Knowledge and skills gap

- Insufficient training on fertigation, system maintenance, and IPM leads to misuse or abandonment of technologies.
- **Mitigation:** scale hands-on training, seasonal refresher courses, and demonstration plots; embed simple decision aids (fertigation schedules, pest thresholds) in extension materials.

Service and infrastructure constraints

- Limited availability of installation and repair services for drip systems and a lack of custom hiring centres for small mechanization tools reduce practical accessibility.
- **Mitigation:** incentivize village-level agri-service providers, promote youth-led enterprises for installation and maintenance, and develop local spare-parts networks.

Market and risk factors

- Price volatility and weak market linkages reduce incentives to invest in quality-enhancing technologies.
- **Mitigation:** strengthen aggregation, contract arrangements, and market information services to improve price realization and reduce perceived risk.

Comparison with other regions

Regional consistency

- Adoption patterns in East Champaran mirror those reported from neighbouring districts in Uttar Pradesh and West Bengal: high uptake of hybrids and mulching, low uptake of drip irrigation and IPM, and yield gains of 20-35% where modern packages are implemented.

Key lessons from adjacent areas

- Regions with stronger FPO activity, better access to subsidies, and active extension networks show faster diffusion of capital-intensive technologies.
- Where input supply chains and bioagent markets are well developed, IPM adoption improves markedly.

Implications for East Champaran

- Replicating successful institutional arrangements from neighbouring districts such as input aggregation, village service providers, and targeted subsidy delivery can accelerate adoption of under-utilized technologies in East Champaran.

Sustainability and environmental implications**Positive environmental outcomes**

- **Water conservation:** Drip irrigation reduces field losses from evaporation and runoff, lowering irrigation water demand and easing pressure on groundwater resources when managed properly.
- **Reduced chemical load:** Integrated Nutrient Management decreases reliance on synthetic fertilizers, reducing nutrient leaching and downstream water pollution.
- **Biodiversity and ecosystem services:** IPM lowers synthetic pesticide use, helping conserve beneficial insects and pollinators and supporting on-farm ecological balance.
- **Soil health:** Long-term adoption of INM and organic amendments increases soil organic carbon and microbial activity, improving resilience and productivity.

Trade-offs and risks

- **Plastic mulch disposal** poses environmental hazards if not managed; non-biodegradable plastics can contribute to soil and water contamination.
- **Energy use and emissions:** Pumping for micro-irrigation and manufacture/disposal of inputs have embedded energy costs that must be considered.
- **Misuse risk:** Poorly designed fertigation or incorrect IPM implementation can still cause nutrient runoff or pest resurgence.

Sustainability recommendations

- Promote biodegradable mulch options and organized plastic collection and recycling.
- Combine water-saving technologies with renewable energy solutions (solar pumps) to reduce carbon footprint.
- Emphasize training on correct fertigation dosing and IPM thresholds to avoid unintended environmental harm.
- Monitor soil health and water quality periodically to track long-term environmental outcomes.

Future research gaps

Despite significant progress in bottle gourd cultivation, several specific research gaps persist that hinder evidence-based scaling and long-term sustainability. Addressing these gaps will require multidisciplinary, participatory, and location-specific studies that combine agronomy, socioeconomics, and environmental monitoring.

Agronomic interactions: drip fertigation × mulching

Gap: Limited location-specific, replicated studies quantifying the combined effects of drip fertigation and plastic/biodegradable mulches on yield, water and nutrient use efficiency, and crop quality under East Champaran conditions.

Priority research questions: What are the synergistic or antagonistic effects of different mulch types with fertigation schedules on yield, fruit quality, and input use? How do these interactions vary across soil textures and seasons?

Suggested methods: Randomized on-farm trials across representative blocks; split-plot designs testing mulch type and fertigation regimes; measurement of soil moisture, nutrient uptake, and crop phenology; cost-benefit and payback analyses.

Long-term soil health under intensive vegetable systems

Gap: Insufficient longitudinal data on how intensive bottle gourd production and associated practices (high fertilizer use, mulching, repeated cropping) affect soil organic carbon, nutrient balance, microbial communities, and soil physical properties.

Priority research questions: How do INM, organic amendments, and reduced tillage influence soil carbon sequestration and nutrient cycling over 3-5 years? What thresholds of fertilizer use degrade or sustain soil function?

Suggested methods: Establish permanent monitoring plots with annual soil sampling (SOC, available NPK, micronutrients, bulk density, microbial biomass), paired with crop productivity records and life-cycle assessments.

Cost-effective IPM modules for smallholders

Gap: Few validated, low-cost IPM packages tailored to smallholder resource constraints and local pest complexes. Supply chains for bioagents and farmer capacity for pest monitoring are weak.

Priority research questions: Which combinations of cultural, mechanical, botanical, and microbial controls deliver acceptable pest suppression at minimal cost? What delivery models (KVK kits, FPO aggregation) ensure timely access to bioagents?

Suggested methods: Participatory IPM trials co-designed with farmers; economic threshold studies; on-farm demonstrations comparing conventional, partial IPM, and full IPM packages; value-chain analysis for bioagent distribution.

Climate resilience of hybrids and management windows

Gap: Limited multi-season, multi-location evaluation of hybrid performance under heat stress, erratic rainfall, and waterlogging typical of the eastern Indo-Gangetic plains.

Priority research questions: Which hybrids and management combinations (short-duration varieties, planting dates, raised beds) minimize yield loss under projected climate extremes? How do phenology and pest/disease dynamics shift with changing weather patterns?

Suggested methods: Multi-year varietal trials across agro-ecological zones; controlled stress experiments (heat, waterlogging); integration of weather-based advisories and phenology models; farmer participatory varietal selection.

Socio-economic and adoption dynamics

Gap: Limited understanding of the socio-economic drivers and institutional constraints that determine differential

adoption across blocks, especially among small and marginal farmers.

Priority research questions: How do credit access, market linkages, gender roles, and risk perceptions influence uptake of capital-intensive technologies? What incentive structures accelerate adoption while protecting vulnerable households?

Suggested methods: Mixed-methods studies combining household surveys, discrete choice experiments, and qualitative interviews; impact evaluation of subsidy, credit, and service-provider models.

Monitoring, scaling pathways, and policy evaluation

Gap: Lack of standardized metrics and monitoring frameworks to evaluate technology performance, environmental impacts, and scaling outcomes.

Priority actions: Develop a simple monitoring toolkit (adoption index, water and nutrient use indicators, soil health score) and pilot it through KVKs and FPOs. Conduct policy simulations to assess subsidy targeting, input regulation, and support for agri-service enterprises.

Implementation approach and priorities

- **Short term (1-2 years):** Launch participatory on-farm trials for drip × mulch and IPM modules; develop monitoring protocols and farmer training materials.
- **Medium term (3-5 years):** Maintain soil health monitoring plots; run multi-location hybrid resilience trials; evaluate economic models for service provision.
- **Cross-cutting:** Engage KVKs, ATMA, FPOs, and local youth enterprises in co-design; ensure gender-sensitive sampling; integrate remote sensing and weather data where feasible.

Filling these gaps with rigorous, farmer-centred research will improve the relevance and scalability of modern bottle gourd technologies, strengthen climate resilience, and ensure sustainable productivity gains for smallholder systems in East Champaran.

Conclusion

The evidence synthesized in this review shows that modern cultivation practices have substantially improved productivity, profitability, and resource efficiency of bottle gourd systems in East Champaran. Hybrid seeds, mulching, integrated nutrient management (INM), and trellising have delivered the most immediate and visible benefits, driving rapid uptake where market access and input supply exist. In contrast, drip irrigation and integrated pest management (IPM) remain under-adopted because of high upfront costs, weak supply chains, and limited farmer capacity.

Sustained gains will depend on coordinated action across technology, policy, and extension: scaling must combine demonstrable on-farm benefits with easier access to finance, reliable inputs, and continuous capacity building so that intensification is both productive and sustainable.

Future Prospects

The future trajectory for bottle gourd in East Champaran lies in integrated packages rather than isolated technologies. Priority directions are:

- **Systems integration:** Combine short-duration, climate-resilient hybrids with mulching, INM, trellising, and targeted micro-irrigation to maximize yield stability and marketability.

- **Affordable micro-irrigation:** Development and dissemination of low-cost, modular drip kits and pay-per-use service models will lower financial barriers.
- **Contextual IPM:** Locally adapted, low-cost IPM modules backed by reliable bioagent supply chains can reduce pesticide dependence and protect beneficial fauna.
- **Institutional innovation:** Strengthening FPOs, agri-service providers, and digital extension platforms will accelerate input aggregation, mechanization services, and market linkages.
- **Climate resilience:** Align planting windows, short-duration hybrids, and raised-bed/mulch practices with weather advisories to reduce crop failure risk under increasing climate variability.

Recommendations

1. The government should increase financial support and develop simplified loan programs to help individuals acquire drip irrigation systems.
2. The research team should conduct comprehensive field experiments to assess the combined effects of mulching, fertigation, and integrated pest management (IPM) practices.
3. The organization needs to establish programs that support Farmer-Producer Organizations (FPOs) and agri-service centers to ensure efficient input distribution for their operations.
4. The program should include the establishment of farmer field schools, which would provide students with practical learning opportunities.

Acknowledgements

The author expresses sincere gratitude to Dr. Samir Ebson Topno, Assistant Professor, Department of Horticulture, NAI, SHUATS, Prayagraj, for his invaluable guidance, encouragement and continuous support throughout the preparation of this review article. The author gratefully acknowledges the cooperation of the farmers of East Champaran, whose field-level insights and practical experiences significantly enriched the quality of this study. Appreciation is also due to KVK Motihari and ATMA East Champaran for providing important district-level data and reports. The author conveys special thanks to Sonal Shikha for her constant support, motivation, and assistance during the preparation of this manuscript. Her help contributed meaningfully to the successful completion of this work.

References

1. Chatterjee R. Biofertilizer application and nutrient uptake in bottle gourd. *J Org Agric.* 2018;5(3):181-190.
2. Choudhary R, Sharma P. Performance of cucurbitaceous hybrids under eastern Indo-Gangetic plains. *Veg Sci.* 2021;48(1):37-42.
3. Government of Bihar. Horticulture statistics at a glance - Bihar. Patna (India): Government of Bihar; 2023.
4. ICAR-Indian Institute of Vegetable Research (IIVR). Annual report on cucurbit crop improvement. Varanasi (India): ICAR-IIVR; 2023.
5. Kumar H, Singh V. Effect of micro-irrigation systems on vegetable productivity in eastern India. *J Agri-Water Econ.* 2020;12(4):55-63.

6. Kumar R, Singh A, Verma S. Climate-smart interventions for vegetable production in eastern India. *Indian J Agric Sci.* 2021;91(8):1185-1191.
7. Krishi Vigyan Kendra (KVK) Motihari. Annual report on vegetable cluster development, East Champaran. Motihari (India): KVK; 2023.
8. Meena RS, *et al.* Role of microbial inoculants in improving vegetable crop performance. *Soil Biol Biochem.* 2021;156:108116.
9. Mohapatra S, Behera T. Influence of mulches on yield of cucurbit vegetables in eastern India. *J Environ Biol.* 2021;42(5):1123-1129.
10. Narayan S, *et al.* Water use efficiency under drip irrigation for cucurbit crops. *J Soil Water Conserv.* 2022;21(2):120-126.
11. Patel N, Rajput TBS. Drip irrigation and fertigation impact on growth and yield of cucurbits. *Agric Water Manag.* 2018;205:30-38.
12. Prasad B, *et al.* Effect of integrated nutrient management on productivity and soil health in cucurbitaceous vegetables. *Indian J Agric Sci.* 2020;90(6):1100-1106.
13. Rai M, Pandey S, Kumar S. Post-harvest management of cucurbit vegetables for quality and shelf life. *J Postharvest Technol.* 2019;7(2):45-52.
14. Sharma A, Mehta N, Joshi R. Effectiveness of extension approaches in technology adoption among vegetable growers. *J Ext Educ.* 2022;34(4):7015-7022.
15. Singh AK, Maurya RP. Evaluation of improved varieties and hybrids of bottle gourd for yield and quality. *Indian J Hortic.* 2019;76(2):250-256.
16. Singh D, Patel R, Yadav P. Impact of farm mechanization on labor use and cost of cultivation in vegetables. *Agric Econ Res Rev.* 2020;33(1):75-82.
17. Singh K, Yadav R. Effect of plastic mulching on soil temperature, weed control and yield of bottle gourd. *Pharma Innov J.* 2020;9(12):255-259.
18. Singh P, Mishra D. Vegetable-based farming systems in Bihar: Status and opportunities. *J Farming Syst Res Dev.* 2022;28(1):85-94.
19. Verma P, Choudhary M, Singh S. Soil health and sustainability under integrated nutrient management in vegetables. *J Sustain Agric.* 2021;45(3):289-301.