



SMART GREENHOUSE AS A PATHWAY TO AGRIBUSINESS DEVELOPMENT

Adoption, Economic Feasibility and Constraints in Bareilly District, Uttar Pradesh

¹Arya Pratap Singh, ²Ashish Samarpit Noel

^{1,2}Department of Agricultural Economics,

^{1,2}Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj, Uttar Pradesh, India

Corresponding author: Arya Pratap Singh (email: to be added)

Abstract : Smart greenhouses, which combine Internet of Things (IoT) sensors, automated irrigation and fertigation, climate control and cloud-based monitoring, offer a route from subsistence open-field farming to high-value commercial agribusiness. This study assesses the status, productivity gains, economic feasibility and adoption constraints of smart greenhouse technology in Bareilly District of Uttar Pradesh. Primary data were collected in 2025-26 from 120 respondents (progressive farmers, traditional farmers, agribusiness entrepreneurs and key informants) across five blocks (Baheri, Faridpur, Nawabganj, Meerganj and Aonla) using a multi-stage sampling design and structured schedules. Descriptive statistics, benefit-cost analysis, Garrett ranking and SWOT analysis were used. Adoption was very low: 48.3 per cent of respondents practised open-field cultivation only, and just 3.3 per cent operated fully integrated smart greenhouses. Tomato yield rose from 8.2 tonnes per acre in open fields to 17.8 tonnes under a full smart greenhouse (+117.1 per cent), and water use fell from 620 to 195 litres per kg of produce (68.5 per cent saving). Capsicum under a smart greenhouse gave a benefit-cost ratio (BCR) of 2.18 against 1.34 in open fields. The establishment cost was about Rs. 38 lakh per acre. Garrett ranking identified high initial investment, lack of technical skill, unreliable electricity, and poor internet connectivity as the four most serious constraints. The paper recommends smart-technology-inclusive subsidies, a demonstration and training centre at KVK Bareilly, concessional credit, reliable agricultural power supply, FPO-led collective investment, and a dedicated greenhouse produce marketing platform.

IndexTerms - smart greenhouse, protected cultivation, IoT, agribusiness, benefit-cost ratio, Garrett ranking, Bareilly, Uttar Pradesh

I. INTRODUCTION

Agriculture and allied activities support more than half of India's population, yet traditional farming is increasingly strained by shrinking and fragmented holdings, falling water tables, climate variability, labour migration and rising input costs. Uttar Pradesh is the most populous state and a leading producer of cereals, sugarcane, potato and vegetables. Bareilly District, in the Rohilkhand region, has fertile alluvial soil, a good irrigation network from the Ramganga and Baur rivers, and proximity to large urban markets. However, average holdings are small, most farmers rely on open-field cultivation, and farm-gate price realisation is weak.

A smart greenhouse is a controlled-environment production system in which IoT sensors monitor temperature, humidity, soil moisture, CO₂, light and nutrient status, and automated equipment adjusts irrigation, fertigation, ventilation and cooling in response. The farmer can supervise the system remotely through a mobile application. Countries such as the Netherlands, Israel and Japan have shown very high resource productivity under such systems. In India, protected cultivation has expanded under the National Horticulture Mission (NHM) and the Mission for Integrated Development of Horticulture (MIDH), but most of the growth is concentrated in states such as Maharashtra, Gujarat, Karnataka and Himachal Pradesh. Uttar Pradesh is a relatively new entrant.

In Bareilly District, smart greenhouse activity is at an early stage. A few private firms supply polyhouse and micro-irrigation equipment, some hydroponic units have been established, and Krishi Vigyan Kendra (KVK) Bareilly runs demonstrations on protected cultivation. Tomato, capsicum, cucumber, leafy vegetables, rose and gerbera are the main crops grown under protected structures. Despite the potential, no comprehensive district-level study of smart greenhouse agribusiness exists for Bareilly. This paper addresses that gap with four objectives:

1. To study the socio-economic profile of the respondents.
2. To analyse the role of smart greenhouses in enhancing productivity and resource efficiency.
3. To examine the economic feasibility of smart greenhouse cultivation.
4. To identify the constraints in adoption and assess the future potential of smart greenhouses for sustainable agribusiness and agripreneurship.

II. REVIEW OF LITERATURE

Research consistently links the integration of IoT, sensors and artificial intelligence with improved greenhouse performance. Shamshiri et al. (2018) reviewed greenhouse microclimate evaluation and control, and Bersani et al. (2022) reported that IoT-based

monitoring lowers energy consumption and labour cost compared with manual management. Farooq et al. (2022), in a systematic review of IoT-based smart greenhouses, found that energy efficiency and reliable long-range communication remain the main unresolved technical challenges. Maraveas (2023) reviewed AI applications, including computer-vision-based crop health monitoring and machine-learning yield prediction, and Javaid et al. (2022) argued that smart greenhouses work best when embedded in a wider Agriculture 4.0 ecosystem of market linkages and institutional support.

Indian studies emphasise economics and adoption barriers. Pachiyappan et al. (2022) found that protected cultivation of high-value vegetables gave substantially higher net returns than open-field cultivation, and that access to affordable institutional credit was critical for small farmers. Kumar et al. (2020) reported favourable benefit-cost ratios for smart greenhouse crops but noted unreliable electricity and weak connectivity as constraints. Meena et al. (2018) and Singh and Tiwari (2019) identified high initial investment and lack of technical knowledge as the principal barriers to adoption among small farmers. Sharma et al. (2021) documented how technology-driven farming attracts youth to agriculture, and Zhang et al. (2022) raised concerns about data ownership and cybersecurity in smart agriculture. Marketing frameworks for horticultural produce, including price spread and marketing efficiency, are drawn from Acharya and Agarwal (2019).

While these studies cover technology, economics and adoption in general, district-level evidence from western Uttar Pradesh, which combines adoption status, productivity, resource efficiency, cost-return and constraint ranking, is scarce. This paper contributes such evidence for Bareilly.

III. RESEARCH METHODOLOGY

A. Study area

Bareilly District lies in the Rohilkhand Division of western Uttar Pradesh between 28.12°N and 28.83°N latitude and 79.0°E and 79.75°E longitude. It covers 4,120 square kilometres, with 15 tehsils and 897 revenue villages, and is bounded by Bijnor, Badaun, Pilibhit and Rampur districts. The climate is sub-tropical, with hot summers (March-June), a monsoon season (July-September) and cool winters (November-February). Average annual rainfall is about 1,000 mm. The terrain is fertile Terai and Bhabhar alluvial plain.

B. Sampling design

A multi-stage sampling design was used. Bareilly District was selected purposively. Five development blocks (Baheri, Faridpur, Nawabganj, Meerganj and Aonla) were purposively selected on the basis of (i) the presence of greenhouse or protected cultivation structures, (ii) documented agri-tech activity in KVK Bareilly records, and (iii) geographic spread across the district. Three villages were then selected at random from each block. Respondents were selected using a combination of purposive and snowball sampling. The total sample of 120 comprised 60 progressive farmers engaged in or considering greenhouse cultivation, 30 traditional open-field farmers for comparison, 15 agribusiness entrepreneurs and existing greenhouse operators, and 15 key informants (KVK and horticulture officials, bank officials and input dealers), distributed equally across the five blocks. Bareilly Mandi was the primary market, and the Nawabganj local market the secondary market.

C. Data and period

Primary data were collected through personal interviews using structured schedules and field observation at existing greenhouse sites during 2025-26. Secondary data came from the District Statistical Handbook of Bareilly, KVK Bareilly reports, the UP Horticulture Department, NABARD reports and published literature.

D. Analytical tools

Socio-economic variables were analysed with frequencies and percentages. The economic feasibility of capsicum cultivation was evaluated through the benefit-cost ratio (Eq. 1):

$$\text{BCR} = \text{Gross Returns} / \text{Total Cost of Production} \quad (1)$$

Adoption constraints were ranked using Garrett's technique (Garrett and Woodworth, 1969). Each rank was converted to a percentage position (Eq. 2):

$$\text{Percentage position} = 100 (R_{ij} - 0.5) / N_j \quad (2)$$

where R_{ij} is the rank given to the i -th constraint by the j -th respondent and N_j is the number of constraints ranked by the j -th respondent. Positions were converted to scores using Garrett's table, and constraints were ranked by their mean score. A SWOT analysis was used for a strategic assessment of the sector.

IV. RESULTS AND DISCUSSION

A. Socio-economic profile of respondents

Table 1. Socio-economic profile of respondents (n = 120)

Variable	Category	Respondents	%
Land holding	Marginal (<1 ha)	40	33.3
	Small (1-2 ha)	46	38.3
	Semi-medium (2-4 ha)	24	20.0
	Medium (4-10 ha)	8	6.7
	Large (>10 ha)	2	1.7
Age	Young (20-35 yrs)	52	43.3

Variable	Category	Respondents	%
	Middle (36-50 yrs)	46	38.3
	Old (>50 yrs)	22	18.3
Education	Illiterate	22	18.3
	Primary	26	21.7
	Junior high	28	23.3
	High school	20	16.7
	Intermediate	14	11.7
	Graduate and above	10	8.3
Gender	Male	96	80.0
	Female	24	20.0
Social category	General	62	51.7
	OBC	38	31.7
	SC/ST	20	16.7
Family type	Nuclear	78	65.0
	Joint	42	35.0
Religion	Hindu	88	73.3
	Muslim	26	21.7
	Christian	4	3.3
	Others	2	1.7

Small and marginal holders together made up about 71.7 per cent of respondents, so affordable finance and subsidy support are central to any adoption strategy. Young and middle-aged farmers accounted for 81.6 per cent of the sample, indicating a working-age community that is potentially receptive to new technology. About 81.7 per cent of respondents were literate, but most had only school-level education, which calls for simple, hands-on training. Women were 20 per cent of respondents, reflecting male-dominated decision-making but also scope for gender-sensitive extension. Participation across social and religious groups suggests that interest in smart greenhouse agribusiness is not confined to any one community. Nuclear families predominated (65 per cent), which makes access to credit and extension services even more important, since such households have limited family labour to fall back on.

B. Adoption status

Table 2. Status of smart greenhouse technology adoption

Technology level	Description	Respondents	%
No adoption	Open-field cultivation only	58	48.3
Basic polyhouse	Polyethylene cover, no automation or sensors	34	28.3
Intermediate	Drip irrigation and basic sensors	14	11.7
Semi-smart	Automated irrigation, partial IoT monitoring	10	8.3
Smart greenhouse	Full IoT, AI and climate automation	4	3.3
Total		120	100.0

Nearly half of the respondents had no protected structure and only 3.3 per cent operated a fully integrated smart greenhouse. Awareness of greenhouse technology is growing, but the full potential of smart systems remains largely untapped.

C. Productivity and resource efficiency

Table 3. Tomato yield across technology levels (tonnes per acre per season)

Technology level	Yield (t/acre)	Increase over open field (%)
Open field	8.2	Baseline
Basic polyhouse	11.4	39.0
Intermediate greenhouse	13.6	65.9
Semi-smart greenhouse	15.2	85.4
Smart greenhouse (full)	17.8	117.1

Yield rose steadily with each step up in technology, and the full smart greenhouse more than doubled the open-field yield. This agrees with the productivity gains reported in the literature (Shamshiri et al., 2018; Kumar et al., 2020).

Table 4. Water use efficiency across cultivation systems

Cultivation system	Water use (litres/kg)	Saving over open field (%)
Open field (flood irrigation)	620	Baseline
Basic polyhouse (drip)	380	38.7
Semi-smart greenhouse	260	58.1
Smart greenhouse (precision irrigation)	195	68.5

Precision irrigation and fertigation cut water use by 68.5 per cent. This matters in a district where groundwater depletion from water-intensive sugarcane and paddy is a growing concern. Shifting part of the area to protected vegetable and flower cultivation can reduce the district's agricultural water footprint.

D. Economic feasibility

Table 5. Estimated cost of establishing a smart greenhouse (per acre)

Component	Cost (Rs. lakh)	% of total
Civil structure (GI frame, polyfilm, foundation)	8.50	22.4
IoT sensors and monitoring system	3.20	8.4
Climate control (fan-pad / HVAC)	6.80	17.9
Automated irrigation and fertigation	4.50	11.8
Electrical works and power backup	3.80	10.0
Software platform and connectivity	1.80	4.7
Planting material and initial inputs	2.40	6.3
Land development and levelling	2.00	5.3
Contingency charges	1.65	4.3
Working capital for first season	3.35	8.8
Total	38.00	100.0

The establishment cost of about Rs. 38 lakh per acre is far beyond the means of most small and marginal farmers. The MIDH subsidy of 50 per cent of project cost (up to Rs. 14 lakh per beneficiary for polyhouse construction) does not adequately cover IoT, software and automation components, which is an important policy gap.

Table 6. Cost and returns of smart greenhouse capsicum (1 acre, one year)

Particulars	Amount (Rs.)
Seeds and planting material	42,000
Fertilizers and nutrients (fertigation)	38,000
Crop protection chemicals	16,000
Labour (planting, harvesting, grading)	68,000
Electricity and water	32,000
Packaging and transport	24,000
Miscellaneous variable expenses	12,000
Total variable cost (A)	2,32,000
Depreciation on structure (15-year life)	1,80,000
Interest on capital at 12% per annum	45,600
Rental value of land	30,000
Total fixed cost (B)	2,55,600
Total cost of production (A+B)	4,87,600
Yield (14.8 t at Rs. 72/kg) - gross returns	10,65,600
Net returns	5,78,000
Benefit-cost ratio	2.18
BCR, open-field capsicum	1.34

Smart greenhouse capsicum returned Rs. 2.18 for each rupee of cost, against Rs. 1.34 in open-field cultivation. These results are consistent with earlier studies reporting that protected cultivation of high-value vegetables outperforms open-field cultivation (Kumar et al., 2020; Pachiyappan et al., 2022).

E. Constraints in adoption

Table 7. Constraints in adoption of smart greenhouse technology (Garrett ranking)

Constraint	Mean Garrett score	Rank
High initial investment and capital cost	71.24	I
Lack of technical knowledge and operational skill	65.18	II
Unreliable or inadequate electricity supply	60.34	III
Poor internet and mobile connectivity	57.82	IV
Limited access to institutional credit	52.46	V
Lack of awareness of government subsidy schemes	48.72	VI
Absence of organised marketing channels	44.38	VII
Risk of total failure due to technology breakdown	41.16	VIII
High maintenance cost, scarcity of skilled technicians	38.54	IX
Data privacy and cybersecurity concerns	32.18	X

Capital cost was the most serious constraint, followed by lack of technical skill. Unreliable electricity and poor connectivity ranked third and fourth, which reflects the fact that climate control, pumps, sensors and remote monitoring all depend on continuous power and internet access; even short outages can stress the crop. Limited credit access (banks lack standard appraisal norms for smart greenhouse projects), unawareness of subsidies and weak marketing channels followed. Data privacy ranked lowest, though it has been highlighted as a long-term concern in the wider literature (Zhang et al., 2022).

F. SWOT analysis

Table 8. SWOT analysis of smart greenhouse agribusiness in Bareilly District

Factor	Key points
Strengths	Fertile alluvial soil; horticultural tradition; proximity to Bareilly city market; good road and rail links; KVK demonstration support; government schemes (NHM, MIDH); growing agri-tech ecosystem
Weaknesses	Very high capital cost; low awareness; poor power and internet; skill gap; fragmented holdings; inadequate credit; subsidy framework excludes smart components
Opportunities	Rising urban demand for off-season premium vegetables; Digital Agriculture Mission; interest of educated youth; organised retail and e-commerce; NABARD and bank credit; export potential for flowers; PPP models
Threats	High energy cost; technology failure and maintenance cost; data privacy concerns; competition from more advanced states; rising cooling demand under climate change; subsidy policy uncertainty; price fluctuations

The district's strengths and opportunities create a favourable environment, but internal weaknesses in capital, infrastructure, awareness and skills must be addressed through targeted policy to convert opportunity into adoption.

G. Future potential for agribusiness and agripreneurship

Smart greenhouses create year-round employment in nursery management, transplanting, harvesting, grading, packaging, cold storage, transport and equipment maintenance. They also open space for rural enterprises such as grafted-seedling nurseries, mobile advisory services and aggregation and marketing firms. Flowers such as rose and gerbera are an especially promising segment because fan-and-pad cooling can maintain the 18-25°C range they require. At present most greenhouse produce moves through the Bareilly mandi, where buyers rarely pay a premium for controlled-environment production. Direct sales to hotels, restaurants and caterers, FPO-based aggregation, organised retail tie-ups and digital platforms are therefore important for capturing the full premium.

V. CONCLUSIONS AND POLICY IMPLICATIONS

Smart greenhouse technology can transform agribusiness in Bareilly District. It more than doubled tomato yield, saved 68.5 per cent of irrigation water, and gave capsicum a BCR of 2.18 against 1.34 in open fields. Adoption is nevertheless extremely low (3.3 per cent of respondents with full smart systems), and the principal barrier is financial, followed by gaps in technical skills, electricity reliability and internet connectivity. The following measures are suggested:

1. **Revise subsidies.** MIDH and NHM should explicitly cover IoT sensors, monitoring software, climate automation and connectivity, with at least 50 per cent subsidy up to Rs. 20 lakh per beneficiary for fully integrated projects.
2. **Demonstration and training.** KVK Bareilly should set up a Smart Greenhouse Demonstration and Training Centre offering hands-on training in IoT-based monitoring, AI-assisted crop management and business planning.
3. **Credit.** NABARD and regional rural banks should develop dedicated products with concessional interest (6-7 per cent), 10-12 year repayment and an initial moratorium, backed by a district-level credit guarantee fund.
4. **Power supply.** Dedicated agricultural feeders, solar micro-grids and backup support should be prioritised in the study blocks.
5. **Collective investment.** FPOs should be encouraged to invest collectively in greenhouse infrastructure so that small farmers can share capital cost and scale economies.

6. **Marketing.** A dedicated greenhouse produce marketing platform at Bareilly's main market should provide transparent price discovery and links to organised retail and export agencies.
7. **Inclusion.** Gender-sensitive extension and self-help-group-linked finance should be introduced to bring more women into smart greenhouse agribusiness.

Limitations. The study covers one district and a sample of 120 respondents selected partly by purposive and snowball sampling, so findings should be generalised with caution. The cost-return analysis refers to a single crop (capsicum) for a single year.

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