AUGMENTING FARMERS' INCOME THROUGH PROTECTED CULTIVATION

RANJANA ROY | ASHOK GULATI

AUGMENTING FARMERS' INCOME THROUGH PROTECTED CULTIVATION

RANJANA ROY | ASHOK GULATI

Augmenting Farmers' Income through Protected Cultivation

Authors

1. **RANJANA ROY**, Senior Fellow, Indian Council for Research on International Economic Relations, New Delhi
2. **ASHOK GULATI**, Distinguished Professor, Indian Council for Research on International Economic Relations, New Delhi

Published by: Indian Council for Research on International Economic Relations (ICRIER), Core-6A, 4th Floor, India Habitat Centre, Lodhi Road, New Delhi – 110003

ISBN: 978-81-998893-9-2

Table of Contents

LIST OF FIGURES AND TABLES

FIGURES

TABLES

ABBREVIATIONS

AERC	Agro Economic Research Centre
APMC	Agriculture Produce Market Committee
CDB	Coconut Development Board
CIH	Central Institute for Horticulture
FPO	Farmers' Producers Organization
GCA	Gross Cropped Area
GVA	Gross Value Added
GVOA	Gross Value of Output from Agriculture
HMNEH	Horticulture Mission for North East & Himalayan States
HRD	Human Resource Department
IRR	Internal Rate of Return
MIDH	Mission for Integrated Development for Agriculture
MoSPI	Ministry of Statistics and Programme Implementation
NAA	Naphthyl Acetic Acid
NCR	National Capital Region

NHB	National Horticulture Board
NHM	National Horticulture Mission
NMSA	National Mission for Sustainable Agriculture
PFDC	Precision Farming Development Centre
RKVY	Rashtriya Krishi Vikas Yojana

FOREWORD

Agriculture in India is experiencing a gradual structural transformation, with an increasing share of the Gross Value of Output (GVO) derived from non-cereal sectors such as horticulture, livestock and fisheries. Despite this transformation in value composition, the reallocation of cropped area away from cereals toward high-value non-cereal crops has been relatively slow. This deviation underlines a critical structural imbalance within Indian agriculture, where the production system is dominated by cereal-based cropping patterns even as market demand and income opportunities increasingly advocate diversified, high-value agriculture. Addressing this disconnect is crucial for augmenting farm income, improving resource-use efficiency, and encouraging a more resilient and market-oriented agricultural system.

In this context, crop diversification is a crucial pathway for bridging the gap between value generation and land-use patterns. However, diversification alone may not be adequate to guarantee sustained income growth. High-value crops such as fruits and vegetables, while generating greater economic returns, are also more susceptible to climatic erraticism, pest attacks, and market volatility. Therefore, the transition toward high-value agriculture must be supported by technological interventions that can stabilize production and improve productivity. Protected cultivation through polyhouses, shade-net houses, and other controlled environment systems signifies one such critical technological advancement that enables farmers to minimize these constraints.

This report studies the emerging role of protected horticulture in promoting crop diversification and enhancing farmers' income. By placing protected cultivation within the wider process of agricultural transformation, the study underscores how technological innovation can carry forward the shift from traditional cereal-based systems to high-value, market-oriented production. The case of coloured capsicum has been studied as a model crop, given its high market demand, suitability for protected environments, and potential to produce higher returns per unit area.

Drawing on secondary data, policy analysis, and field-level case studies from Haryana and Uttar Pradesh, the report offers a comprehensive evaluation of the economic viability, productivity performance, and institutional ecosystem linked with protected cultivation. The findings suggest that while protected horticulture can considerably improve yields and profitability, its extensive adoption is dependent upon access to affordable credit, technical knowledge, and efficient market linkages.

Overall, the report underlines that the convergence of crop diversification and technological advancement is vital for achieving sustainable income growth in Indian agriculture. Protected cultivation, by enabling year-round production, improving yield stability, and easing integration with high-value markets, holds significant potential to transform the horticulture sector.

I hope that the insights generated from this study will provide valuable guidance to policymakers in designing targeted interventions for scaling up crop diversification through protected cultivation. By identifying key constraints, opportunities, and enabling factors, the study aims to inform evidence-based policy formulation that promotes wider adoption of high-value horticulture. Ultimately, such efforts can contribute to strengthening farmers' income, enhancing agricultural resilience, and fostering a more efficient and market-aligned agricultural system in India.

Shekhar Aiyar
Director and Chief Executive
ICRIER

ACKNOWLEGEMENT

We would like to acknowledge the financial support extended by the Kotak Karma Foundation, which made the preparation of this report, titled "Augmenting Farmers' Income through Protected Cultivation" possible. The study has greatly benefited from the cooperation and insights of diverse stakeholders, including expert consultants, and field practitioners, whose contributions at various stages were invaluable to its completion.

We extend our heartfelt gratitude to **Mr. Pawan Kumar**, **Ms. Anushka Jaiswal**, and **Mr. Shubham Diwedi** for their invaluable cooperation and openness in sharing detailed insights for this study. Their willingness to provide information on cultivation practices, costs, yields, and market experiences greatly enriched the empirical foundation of the report. The field interactions and firsthand experiences shared by them offered critical perspectives on the opportunities and challenges of protected horticulture, enabling a more nuanced and grounded analysis. Their contributions have been instrumental in bridging the gap between theory and practice in this research.

We would like to express our sincere appreciation to **Mr. Priya Ranjan**, Joint Secretary (Horticulture), and **Mr. Billu Yadav**, Deputy Director (Horticulture), for their invaluable support in organising a focused group discussion with farmers at the MIDH Centre. The interaction provided rich, ground-level insights into the functioning of Centres of Excellence (CoEs) and their role in promoting protected cultivation practices. The discussion facilitated a deeper understanding of farmers' experiences, challenges, and expectations from government interventions, particularly in areas such as access to quality planting material, adoption of advanced technologies, and capacity building. Their efforts in bringing together diverse stakeholders significantly strengthened the empirical depth and policy relevance of this study.

We thank **Mr. Rahul Arora** for his assistance in designing the report. The responsibility for the data, analysis, and views expressed in this report as well as any errors rests solely with the authors.

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

India's agriculture is experiencing a gradual structural transformation, with a growing contribution of non-cereal sectors to the Gross Value of Agricultural Output (GVOA), even though cereals still dominate the cropping pattern. Cereal crops constituting around 62 percent of the gross cropped area (GCA), while horticulture crops account for a much smaller share of 11 percent of GCA. However, the share of cereals in total GVOA has reduced from 17.5 percent in triennium ending (TE) 2013–14 to 14 percent in TE 2023-24, the expansion of high-value segments such as horticulture from 19.4 percent to 21 percent (MoSPI, 2023). This indicates a slow and uneven shift in cropped area from cereals to non-cereal crops, underlining structural rigidities within the agricultural system. In this context, crop diversification has emerged as a critical way for enhancing farmers' income, improving resource-use efficacy, and strengthening resilience to climate and market risks. However, diversification into horticulture alone does not promise higher income, as high-value crops persist to be vulnerable to yield variability, pest attacks, seasonality, and price variations. Against this background, technological interventions that boost productivity and stabilize output become vital. Protected cultivation through controlled environments such as polyhouses and shade-net houses characterizes one such technology-driven approach to improving farm productivity and profitability. This study explores the emerging role of protected horticulture in India, predominantly in the context of crop diversification and income augmentation.

Despite the growing demand for high-value agricultural products, the pace of diversification remains unequal across states. Some states such as Andhra Pradesh, Kerala, Tamil Nadu, Jharkhand, have accomplished relatively higher diversification levels, while others mostly those historically associated with the Green Revolution, such as Punjab and Haryana continue to display strong crop concentration in rice–wheat systems. These trends highlight the importance of policy interventions and technological innovations that can support the transition toward high-value agriculture.

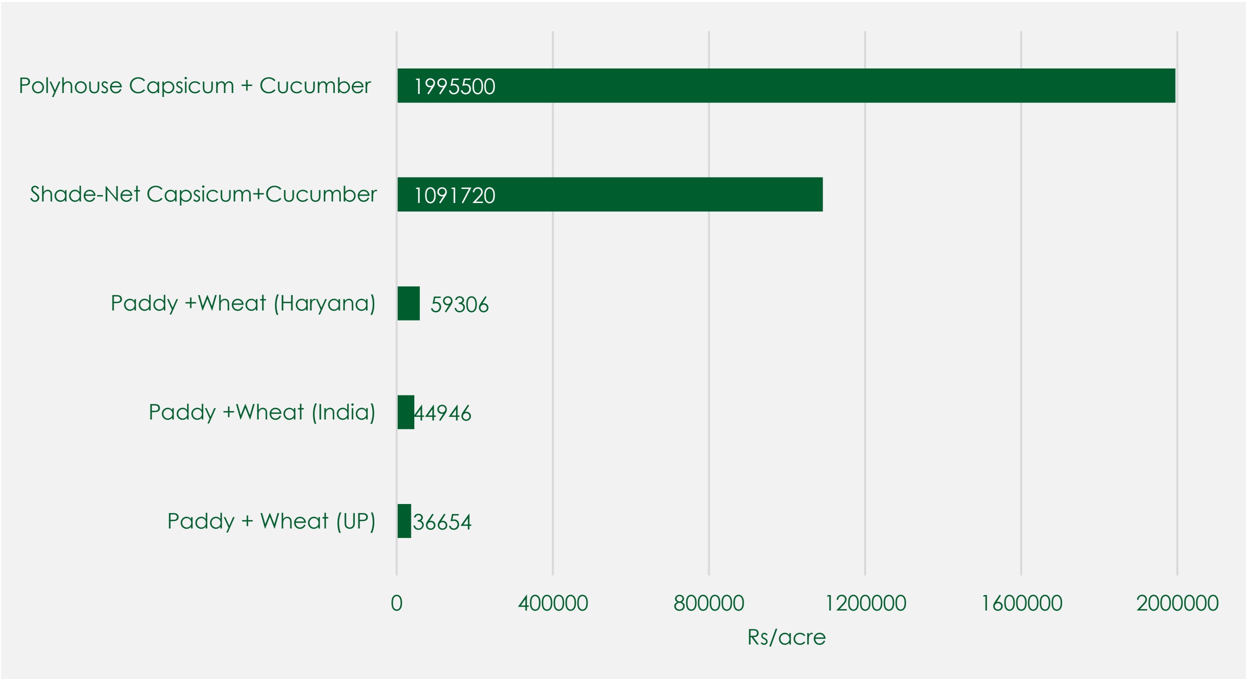
Globally, protected cultivation has expanded rapidly as many countries are committed to improve agricultural productivity and guarantee year-round supply of horticultural products. China with nearly 60 percent of the protected cultivation area worldwide leads the global landscape. In contrast to the widespread adoption of low-cost protected cultivation systems such as those seen in China, the high-tech polyhouse models of Israel and the Netherlands represent a more advanced, precision-driven evolution of controlled environment agriculture. In Israel, high-tech polyhouses are engineered to maximize resource-use efficiency under climatic stress, integrating drip irrigation, fertigation, automated climate control, and sensor-based monitoring to optimize inputs and stabilize yields. Similarly, in the Netherlands, protected cultivation has evolved into a highly sophisticated glasshouse-based system, characterized by fully automated environmental regulation, CO_2 enrichment, artificial lighting, and hydroponic production. These systems emphasize intensive management of crop conditions, enabling year-round production, higher productivity, and superior quality outputs. Together, they illustrate a shift from scale-driven, low-cost structures toward technology-intensive, knowledge-driven systems, where productivity gains are achieved through precision, innovation, and integration with advanced research and market ecosystems. In contrast, the embracing of protected cultivation in India remains relatively restricted, covering only a small proportion of the total cultivated area. However, the technology has been provided through government support programs such as the Mission for Integrated Development of Horticulture (MIDH) and the Centres of Excellence (CoE) with Indo-Israel and Indo-Dutch collaboration. These centres serve as key institutional platforms for promoting high-tech horticulture in India through demonstration, training, and technology dissemination. With 52 centres approved nationwide (36 operational and 16 under development), the programme initiated in 2012 through Indo-Dutch collaboration and further strengthened by partnerships with Israel and Netherlands focuses on improving productivity, quality planting material, and sustainable cultivation practices. These centres provide hands-on training across crops such as vegetables, fruits, and flowers, while showcasing advanced practices including protected cultivation, nursery management, and precision irrigation. The Indo-Israel CoEs, in particular, function as hubs for adapting Israeli technologies to Indian conditions, emphasizing intensive and resource-efficient farming. With a cumulative investment of around Rs. 5 billion, CoEs annually produce over 25 million quality vegetable seedlings and 0.38 million fruit plants, while training more than 1.2 lakhs farmers, thereby significantly contributing to capacity building and technology adoption in the horticulture sector.

The study emphasizes on coloured capsicum as a model crop to examine the economic viability of protected cultivation. Capsicum has emerged as one of the most successful crops grown under polyhouse settings due to its high market demand, adaptability to controlled environments, and potential for making higher returns per unit area. Over the past decade, the area under capsicum cultivation in India has increased considerably, accompanied by improvements in productivity and output. The majority of capsicum output in India comprises of green capsicum cultivated under open-field conditions, while coloured capsicum represents a comparatively small share of total output and is predominantly produced under protected cultivation systems such as polyhouses and shade-net structures. Red and yellow capsicums contain higher levels of vitamin C, vitamin A, and antioxidants than green capsicums. Under MIDH programmes, around 2.64 lakh hectares area has been brought under protected cultivation in the period of 2014-15 to 2022-23 indicating a penetration of less than 0.2 percent of net sown area (NSA) (Lok Sabha Starred Question,2023). The growth has been motivated by technological innovations such as hybrid seeds, fertigation systems, drip irrigation, and upgraded crop management practices. Besides, rising urban demand for high-quality vegetables and the development of organized retail markets including online platforms have created new market opportunities for producers.

To examine the economic performance of protected cultivation, the study presents detailed case studies of capsicum cultivation under polyhouse and shade-net systems in Haryana and Uttar Pradesh. These states offer an exciting context for studying diversification because they are traditionally dominated by rice–wheat cropping systems but are gradually exploring high-value horticulture as an alternative pathway for income growth. Haryana benefits from proximity to major urban markets in the National Capital Region (NCR), while peri-urban clusters in Uttar Pradesh have started implementing protected cultivation technologies through the efforts of young agripreneurs and government support programs. The comparative analysis highlights how aspects such as market access, investment structure, and management practices impact the profitability and sustainability of protected horticulture systems.

The economic analysis shows that protected cultivation generates considerably higher yields and returns compared to traditional open-field farming systems. Polyhouse cultivation of capsicum can achieve significantly higher productivity due to controlled temperature, humidity, and pest management conditions. Higher productivity, combined with improved crop quality and the ability to produce off-season vegetables, allows farmers to attain better market prices. The following figure highlights the substantial profitability advantage of protected cultivation over the conventional paddy–wheat cropping system. Net returns from polyhouse cultivation of capsicum and cucumber are estimated at around Rs. 19.95 lakhs per acre in a year, which is nearly 30 times higher than the paddy–wheat returns in Haryana (Rs. 59,306 per acre) and over 50 times higher than those in Uttar Pradesh (Rs. 36,654 per acre). Even in Haryana, where farmers benefit from an MSP-backed procurement system, returns remain significantly lower than those achievable in production of high value vegetable crops under protected cultivation. Moreover, relatively low-cost options such as shade-net houses also deliver strong financial performance, generating net returns of approximately Rs. 10.9 lakhs per acre.

Figure: Economic Returns: Protected Cultivation vs Traditional Farming, TE 2024-25



Source: Field Information and Cost of Cultivation data, Kharif and Rabi Report, CACP

Financial analysis, including investment appraisal and sensitivity analysis, recommends that despite high initial capital costs, protected cultivation projects can yield lucrative returns over the project life. The results are further supported by Monte Carlo simulation analysis, which validates that the internal rate of return (IRR) remains robust at 54 percent across a range of price, yield, and cost scenarios Sensitivity analysis indicates that in the absence of government subsidies accompanied by unfavourable conditions (yield/price drop), the project's IRR undergoes a significant contraction, declining to approximately 25-35 percent. This underscores the project's high level of dependence on fiscal incentives to maintain its superior profitability profile. This indicates that bureaucratic inefficiency and systemic corruption might function as an informal tax, inflating the net initial investment and delaying capital recovery, which significantly compresses the project's IRR.

Despite these positive economic outcomes, protected cultivation in India faces several challenges. One of the most significant blockades is the high initial investment required for building polyhouses and installing associated irrigation and fertigation systems. Although government subsidies decrease the financial burden, the technology remains capital intensive. Such systems are particularly well-suited to small landholdings, as they enable substantially higher returns per unit of land. However, their adoption is contingent upon access to adequate initial capital investment, which necessitates improved availability of institutional credit, particularly through formal banking channels. In addition, protected cultivation necessitates specialized technical knowledge for managing temperature of the structure, efficient nutrient application, and pest control. Limited technical training and inadequate extension support can therefore obstruct the success of these systems. Marketing limitations also pose significant challenges. Most farmers rely on intermediaries such as commission agents and wholesalers, which decreases their share in the consumer price. Moreover, fluctuations in market prices, seasonal demand patterns, and inadequate cold-chain infrastructure can affect profitability.

The findings of the study point towards important policy implications for scaling up protected horticulture in India. Strong institutional support instruments particularly access to affordable credit, better extension services, and training programs will be vital for empowering wider adoption among small and marginal farmers. Improving market linkages through farmer producer organizations (FPOs), and integration with organized retail platforms can help farmers reap a larger share of consumer prices. Investments in post-harvest infrastructure, including cold storage facilities, grading and packaging centres, and efficient transportation networks, will further enhance the efficiency of horticultural value chains. Finally, policy frameworks should encourage the development of region-specific protected cultivation models that account for local agro-climatic conditions, market demand, and resource availability.

Overall, the study concludes that protected cultivation embodies a promising pathway for promoting crop diversification and augmenting farmers' income in India. By allowing year-round production, improving yield stability, and facilitating integration with high-value markets, protected horticulture can contribute to a more resilient and commercially oriented agricultural system. However, appreciating its full potential will require synchronized efforts involving technological innovation, institutional support, and market development. With appropriate policy interventions and investments, protected cultivation can perform a critical role in transforming Indian agriculture toward a more productive, sustainable, and income-enhancing sector.

Protected Cultivation of Capsicum: Success Stories

Polyhouse Cultivation

Location: Harikhera village, Mohanlalganj Block, Lucknow District, Uttar Pradesh

- Area under Cultivation: 3 acres
- Cost of Installation: Rs. 52 lakhs (Govt Subsidy 17 lakhs) @1 acre
- Yield: 35 tonnes/acre
- Net Return from Capsicum: Rs. 19.5 lakhs/acre
- Net Return (Adjusting for Annualized fixed cost): Rs. 16 lakhs/acre
- Net Return (first three years adjusting loan): Rs. 7.23 lakhs/acre

Polyhouse Cultivation

Location: Gaura village, Mohanlalganj Block, Lucknow District, Uttar Pradesh

- Area under Cultivation: 2.5 acres
- Cost of Installation: Rs. 45.5 lakhs (Govt Subsidy Rs. 20.6 lakhs) @1 acre
- Yield: 24 tonnes/acre
- Net Return from Capsicum: Rs. 14.4 lakhs/acre
- Net Return (Adjusting for Annualized fixed cost): Rs. 11.9 lakhs/acre
- Net Return (first three years adjusting loan): Rs. 5.74 lakhs/acre

Shade Net Cultivation

Location: Sangoha Village, Karnal Block, Karnal District, Haryana

- Area under Cultivation: 3 acres
- Cost of Installation: Rs. 28 lakhs (Govt Subsidy Rs. 18 lakhs) @1 acre
- Yield: 12 tonnes/acre
- Net Return from Capsicum: Rs. 8.92 lakhs/acre
- Net Return (Adjusting for Annualized fixed cost): Rs. 7.92 lakhs/acre
- Net Return (first three years adjusting loan): Rs. 5.4 lakhs/acre

1 INTRODUCTION AND CONCEPTUAL FRAMEWORK

INTRODUCTION AND CONCEPTUAL FRAMEWORK

There has been a gradual shift from traditional cereal-based production system to a diversified high-value agriculture in India in the recent times. This has been motivated by the changing consumption pattern, upcoming urban clusters, and growing per capita income of the population. In terms of cultivable area, cereals still account for the largest share, but a steady shift in horticulture area has been observed. Horticulture crops offer considerably higher return, better market opportunities, and allows sustainable farming practices. However, farmers cultivating horticulture crops face lot of challenges as these crops are sensitive to weather events, and pest attacks . In this context, technological interventions have a crucial role to play in dealing with these challenges and ensuring a sustained level of income.

One such intervention has been in the form of protected cultivation (polyhouses/net houses) that is a specialized, intensive agricultural techniques that produces crops within a controlled or partially adapted environment. The adoption of protected cultivation in horticulture crops has emerged as a lucrative pathway to augment farmers' income. This system of production enables better productivity, uniform quality, and year-round production. Hence, it not only promotes crop diversification but enhances economic feasibility by fetching higher price for better quality output during off-season. Against this backdrop, the study of crop diversification interlinked with technological innovation and evolving market dynamics becomes imperative for identifying structural changes in agriculture and identifying pathways for augmenting farmers' income. The report is organised as follows. The Chapter 1 develops the theoretical framework in detailed manner dovetailing crop diversification, protected cultivation, and farmers' income. Chapter 2 outlines the methodology adopted in the study. Chapter 3 examines the global landscape of protected cultivation, followed by an analysis of India's experience in Chapter 4. Chapter 5 presents Capsicum as a model crop for this particular study analysing its production landscape and the value chain dynamics. In Chapter 6, the report presents the case studies of coloured capsicum produced in protected environment. It encompasses aspects such as productivity performance, cost of cultivation, revenue generated, risk assessment, finance and challenges to scalability. Finally, Chapter 7 synthesises the key findings of the study and prescribes relevant policy solutions.

1.1 LIVELIHOOD DIVERSIFICATION TO AUGMENT FARMERS' INCOME

Livelihood diversification is a critical strategy adopted by rural households to enhance income stability and mitigate risks associated with climatic and economic uncertainties. It encompasses a shift in economic activities, where households engage in multiple sources of income, including farm and non-farm activities. In the Indian context, where 86 percent of farmers belong to the small and marginal category, diversification is an essential pathway for economic resilience and sustainability. Within crop sector, diversification towards high value agriculture including fruits, vegetables, spices, and floriculture offer profitable returns as compared to the traditional crops. This is often demand led, catering to the evolving consumer preferences in the urban and peri-urban markets resulting from rising per capita income. A study by Joshi et al (2004) conducted on South Asia, identified factors like rising per capita income, shifting dietary preferences, urbanization, and infrastructure development as major drivers of crop diversification.

The impact of diversification on rural economy is manifold. It influences farm income by enhancing productivity, optimizing resource use, and improving market competitiveness. It also stimulates rural employment by creating value chains, attracting agro-processing industries, and creating off-farm jobs in transport, storage, and retail. This evolution conforms with the broader development goal of ensuring food and nutritional security, and rural transformation. However, the sector is plagued by various challenges such as lack of working capital among farmers, inadequate infrastructure development in the post-harvest value chain, limited direct market linkages, and the absence of a favourable policy environment, all of which slow down the process of diversification.

At all-India level, there has been gradual transition from traditional farming to high value agriculture, with significant variation across states. Smallholder farmers are more inclined to diversification as a strategy to augment farmers' income especially in underdeveloped regions (Birthal et al., 2020). However, challenges such as price volatility, high input costs, and market risks impact decisions regarding cropping pattern and diversification (Gupta & Tewari, 1985; Priyadarshini & Abhilash, 2020).

The major drivers for crop diversification have varied across states and shaped by factors like market access, infrastructure, and institutional aspects. For instance, in states like Karnataka, Bihar, Jharkhand, Odisha, and West Bengal, expansion of commercial crops has been driven by infrastructural development, irrigation facilities, and accessibility of modern farm implements (Acharya et al., 2011; Kumar et al., 2012). Institutional factors like government schemes, access to credit also played important role in influencing farmers' decision to adopt diversification (Alur & Maheswar, 2018; Joshi et al., 2007). Other major factors that have impacted farmers' cropping decision are road infrastructure, transportation, and input subsidies (Joshi et al., 2007; Vyas, 1996).

Diversifying both within and outside crop sectors offer significant opportunities for enhancing farmers' income in India, especially for small and marginal farmers. With rising demand for high value products such as fruits, vegetables, dairy, poultry, and fisheries, farmers can benefit from better market prices and improved profitability. Moreover, crop diversification helps mitigating the risks associated with monocropping. By diversifying their income sources into livestock and high value crops, farmers can ensure more resilient and sustainable livelihoods, and improve their overall economic wellbeing.

Crop diversification has become a crucial pathway for improving agricultural productivity, augmenting farm income, and ensuring food security. By reducing the risks associated with monoculture farming such as pest attacks, diseases, and market instabilities, diversification boosts the resilience and sustainability of agricultural systems (Neogi & Ghosh, 2022). This strategy has proved to be helpful in drought-prone regions, where crop diversification has improved water-use efficiency and reduce dependence on erratic rainfall (Pattanayak et al., 2023).

The transition to high-value crops such as fruits, vegetables, and oilseeds presents significant economic prospects for Indian farmers. The cultivation of these crops has offered higher profitability, better market linkages, and greater employment opportunities in rural areas (Smith et al., 2019). Additionally, crop diversification ensures a steady supply of a diversified and nutritious food basket, thus strengthening food security goals at the macroeconomic level (Kumar & Gupta, 2015). In the recent years agricultural policy in India has gradually shifted from tonnage centric goals to prioritizing farmers' livelihoods. Given India's diverse agro-climatic conditions, the country holds important potential for crop diversification.

Effectively leveraging this potential can alter agriculture into a more sustainable and profitable sector, addressing economic and environmental challenges.

1.2 LEVEL OF CROP DIVERSIFICATION IN INDIA'S CONTEXT

As discussed in the previous section, Indian agriculture has seen a transition from traditional farming to a more commercialized approach, motivated by developing market conditions, technological advancements, and policy interventions (Kumar & Gupta, 2015). However, the level of diversification remains uneven across regions, necessitating a complete understanding of the factors that form diversification trends.

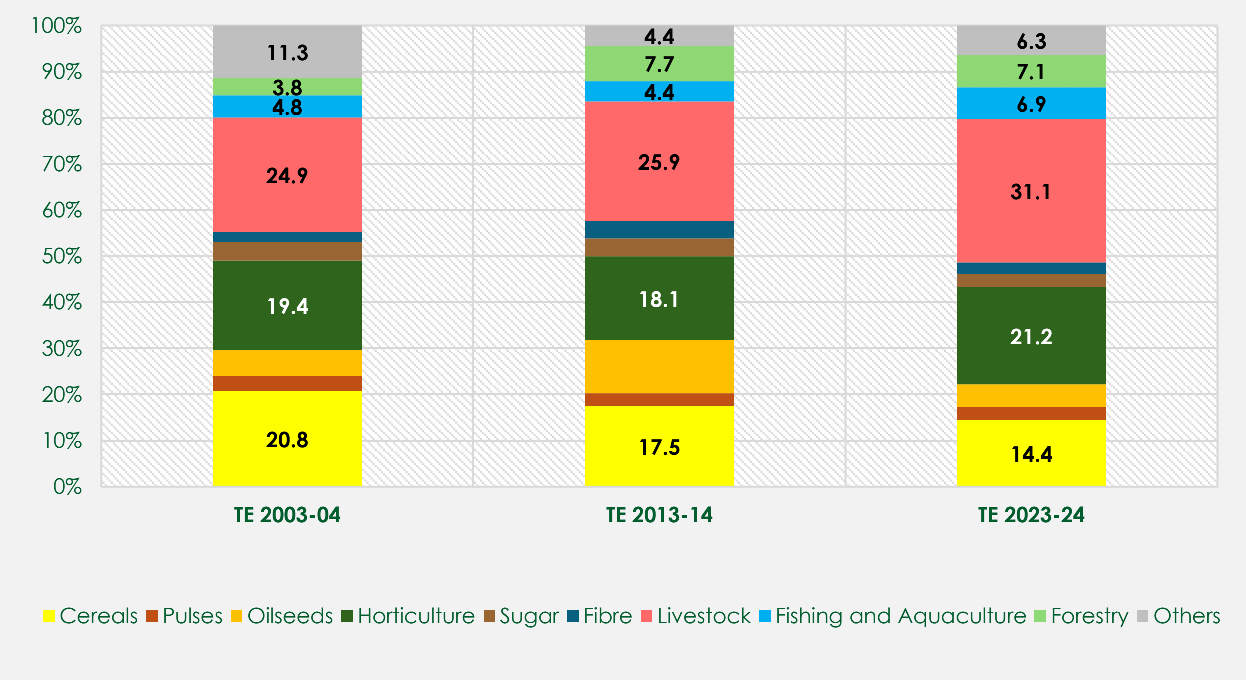
The agriculture and allied sectors continue to play a significant role in the Indian economy, contributing 18.3 percent to the Gross Value Added (GVA) at current prices in the financial year TE2023-24. Crop sector maintains the largest share in the GVO of the agriculture and allied sector. However, the contribution of the crop sector has been observing a steady decline over time, signifying structural changes within the broader agricultural landscape.

In TE2023-24, the crop sector accounted for approximately 48.6 percent of the total GVO of agriculture and allied activities. Within crop sector, cereals contributed 14.4 percent to the Gross Value of Output in Agriculture (GVOA), whereas horticulture[1] contributed a higher share of around 21 percent (**Figure 1.1**). Despite the crop sector's dominant position, its relative drop in share suggests a shift towards diversification within crop sector towards horticulture, and outside crop sector towards livestock and fisheries.

In most of the states F&V constitutes high share in their GVOA. The share is as high as 42 percent in Jammu and Kashmir followed by Himachal Pradesh (35 percent), West Bengal (28 percent), Chhattisgarh (27 percent), and Madhya Pradesh (21 percent).

[1] Horticulture group included fruits, vegetables, spices, and floriculture

Figure 1.1: Composition of Gross Value of Output from Agriculture and Allied Activities, TE 2003-04 to TE 2023-24

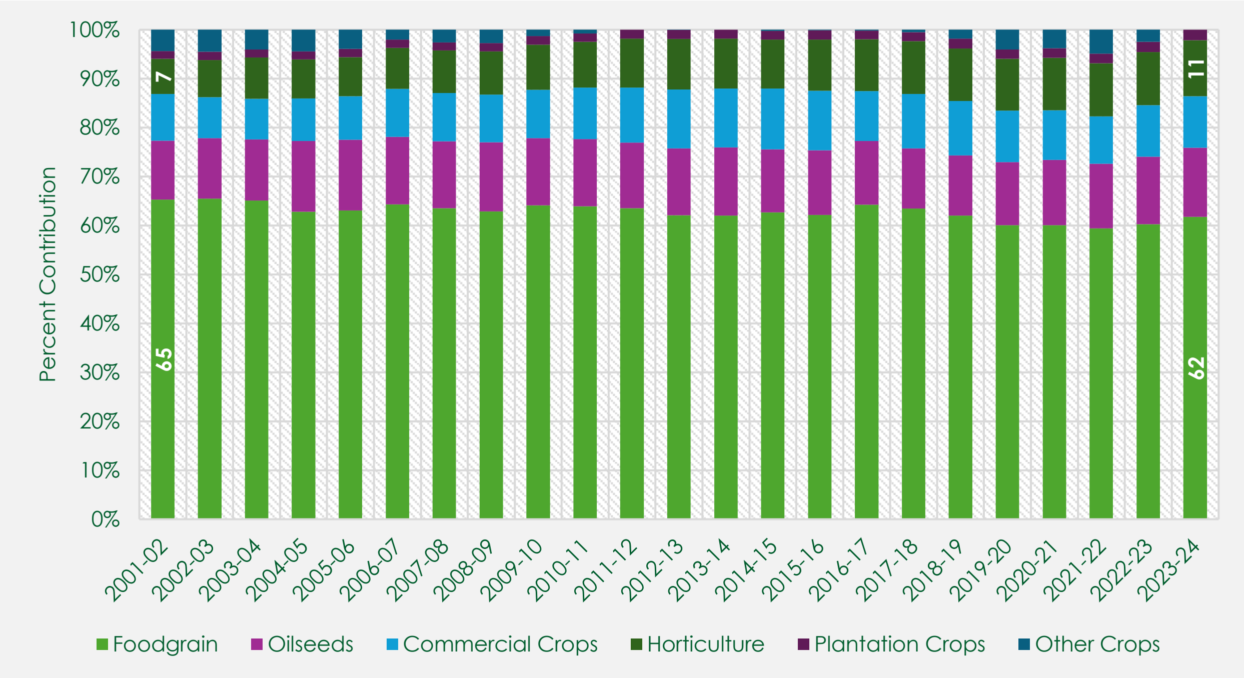


Source: Central Statistical Office (CSO), MoSPI

Despite increasing share of value generated from the non-foodgrain sector, India's agricultural landscape is dominated by food grain cultivation, which accounted for approximately 62 percent of the GCA in the agricultural year 2023-24. This is followed by oilseeds covering 14 percent, commercial crops at 11 percent, and horticulture also constituting 11 percent of the total cropped area (**Figure 1.2**).

An analysis of historical trends reveals a gradual shift in cropping patterns over the past two decades. In 2001-02, food grains occupied around 65 percent of the GCA, which has now declined to 62 percent in 2023-24. This indicates a marginal diversification in the agricultural sector, though the pace of change remains slow. The share of high-value crops, such as fruits, vegetables, and commercial crops, has seen a slight increase, suggesting that diversification is not occurring at a significant scale. This trend underlines the fact that India's agriculture largely dominated by staple food production, with only marginal shifts toward high-value and non-food grain crops. Various factors, comprising of government policies, disintegrated value chain, lack of market infrastructure, and climatic conditions influence these cropping decisions (Roy et al., 2024, Das et al., 2024). Policy intervention in infrastructure development, and technological interventions will fast-track diversification and augment farm income.

Figure 1.2: Cropping Pattern at All-India Level (2001-02 to 2023-24)



Source: MoA&FW

An assessment of state-level patterns reveals a strong association between the share of area under horticulture and the value of agricultural output per hectare of GCA (GVO/ha), highlighting the role of crop diversification toward high-value agriculture. States with a higher proportion of land allocated to horticulture such as Sikkim (62.5 percent), Jammu and Kashmir (46.6 percent), and Himachal Pradesh (38.5 percent) generally exhibit relatively higher levels of value realization per hectare. Similarly, states like Tripura and Jharkhand, which combine moderate-to-high horticulture area shares, record among the highest GVO per hectare, exceeding Rs. 3.5 lakhs, indicating the strong income-enhancing potential of diversification (**Figure 1.3**).

In contrast, states with lower horticulture shares such as Punjab (6.4 percent), Haryana (6.6 percent), and Rajasthan (8.3 percent)tend to have comparatively lower GVO per hectare, reflecting continued reliance on low-value foodgrain systems. The national average, with about 13.11 percent area under horticulture, also corresponds to GVO per hectare of Rs. 1.39 lakhs, further reinforcing this trend (**Figure 1.4**).

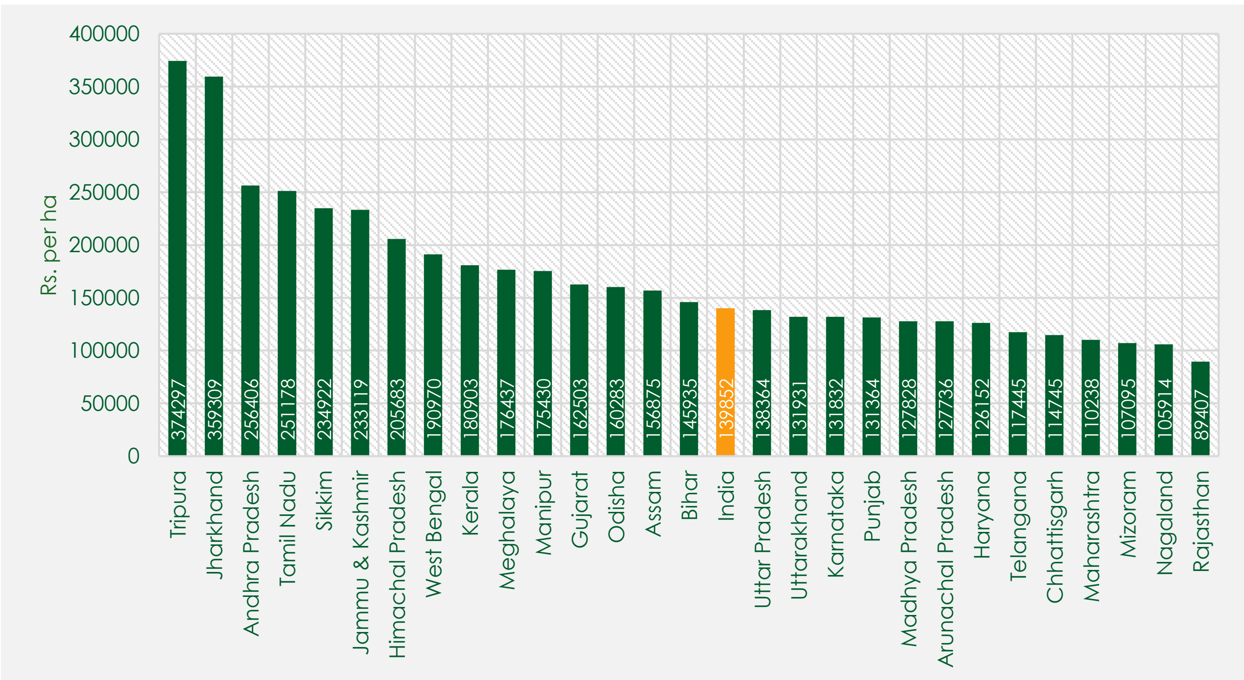
However, the relationship is not perfectly linear. Some states with relatively lower horticulture shares, such as Andhra Pradesh and Tamil Nadu, still achieve high output per hectare due to better market linkages and technology adoption. This suggests that while increasing horticulture area is a critical driver, complementary factors such as infrastructure, value chains, and access to markets play an equally important role.

Literature conforms to these findings reinforcing that the trends in crop diversification in India exhibit considerable regional variation over time.

In states like Punjab, historical policy environment and structural constraints have resulted in strong reliance on staple crops. The availability of high yielding variety of seeds and government procurement mechanism have limited the willingness for diversification among farmers despite having implications for groundwater and soil quality (Deshpande et al, 2007).

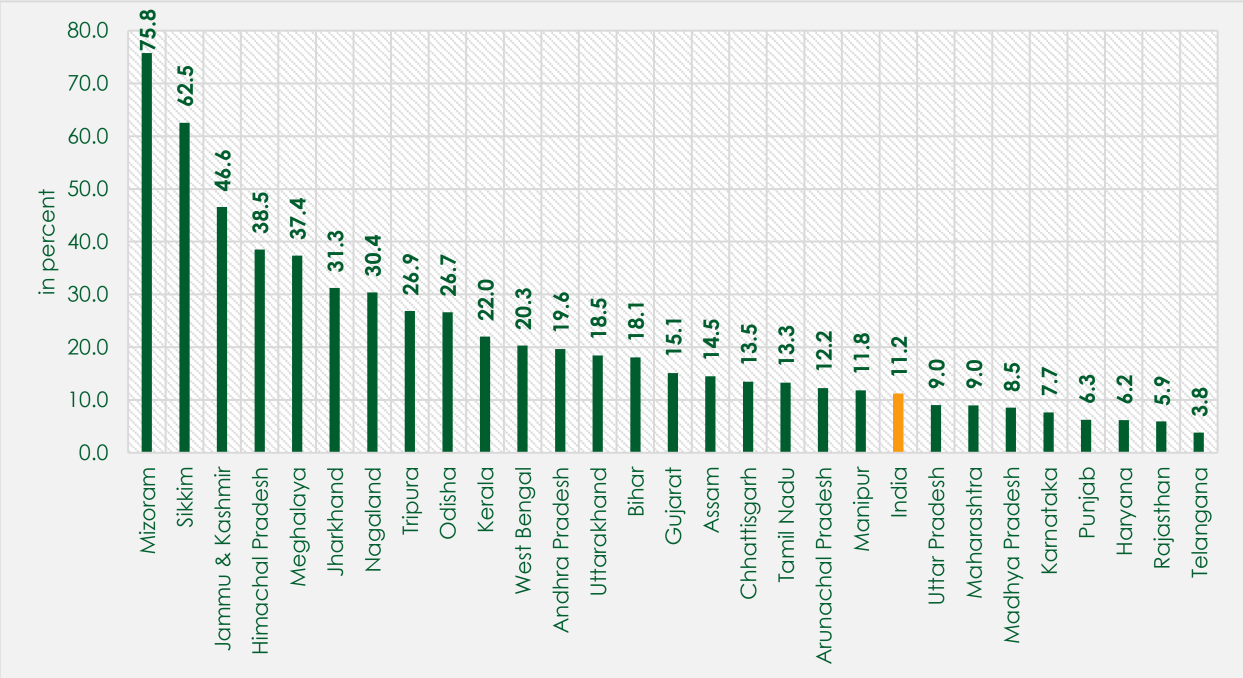
In moderately diversified states like Bihar and UP, positive efforts are steadily gaining power. Bihar has experienced a shift from traditional rice-wheat cropping system towards maize, pulses, and horticulture crops. In Bihar, transition towards horticulture crops is more prevalent for smallholders (Gupta & Kannan, 2024; Kumar et al., 2024).

Figure 1.3: Gross Value of Output from crops per hectare of Gross Cropped Area. TE 2023-24



Source: MoSPI and MoA&FW

Figure 1.4: State-wise Area under Horticulture, 2023-24



Source: MoA&FW

While diversification remains a dominant trend in several states, structural barriers persist, necessitating continuous policy attention to sustain diversification efforts and mitigate risks associated with crop concentration.

The observed patterns of diversification and concentration have important policy implications, particularly in the context of long-term agricultural sustainability, food security, and economic resilience. The increasing diversification trends in Andhra Pradesh, Tamil Nadu, and Kerala align with broader policy objectives for enhancing agricultural sustainability through targeted interventions, including crop rotation schemes and improved market access for non-traditional crops. The continued dominance of specific crops in Punjab underscores the necessity for policy measures for reducing over-reliance on a narrow range of crops. Prior studies have recommended that initiatives such as incentives for alternative cropping systems, investment in value chains for non-traditional crops, and research on sustainable diversification practices could play a pivotal role in fostering a more balanced agricultural system (Deshpande et al., 2007; Smith et al., 2019; Kumar et al., 2024).

1.3 INDIA'S POSITION IN GLOBAL HORTICULTURE

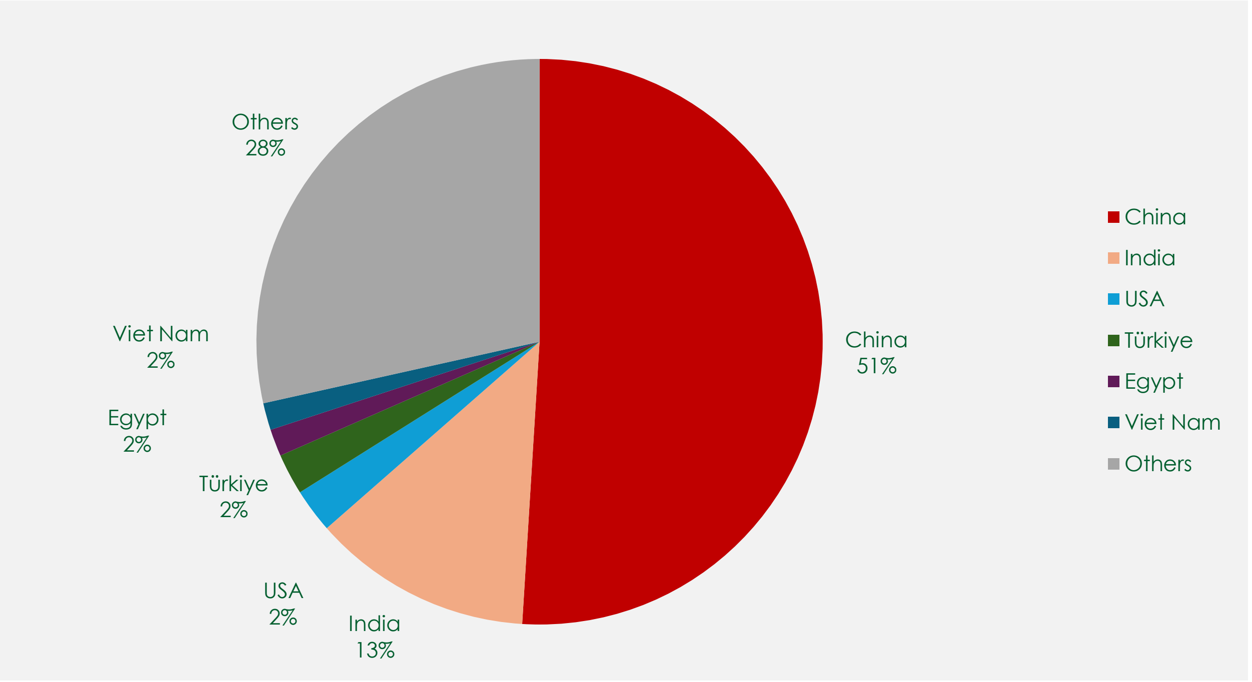
With the increasing worldwide demand for horticultural crops, global policies have been directed towards innovation in agricultural practices, improvements in productivity, and progresses in supply chain efficiency. China is the world's largest producer of fruits and vegetables, followed closely by India. China, India, and Brazil are the major three producers of fruits in the world, contributing 28.5 percent, 11.6 percent, and 4.5 percent of fruit output respectively in TE 2023-24 (FAOSTAT, 2023-24).

In terms of vegetable production, India holds a second position with 12.6 percent share of global output following China which contributes 51 percent of global output. In contrast, the United States and Turkey, Egypt, and Vietnam together account for 8 percent of the world's total vegetable production for the TE 2023-24 (**Figure 1.5**). Despite India's large production base, yield level remains at a lower level compared to other major producing nations. For instance, India's average vegetable productivity is approximately 16 metric tonnes (MT) per hectare, whereas China achieves over 26 MT per hectare (FAOSTAT, 2023-24).

Developed nations such as the Netherlands and the United States remain in an advantageous position from effective logistics, cutting-edge storage infrastructure, and technological interventions, allowing them to maintain higher yield and export volumes. Addressing these gaps is important for India to progress its global competitiveness in the horticulture sector.

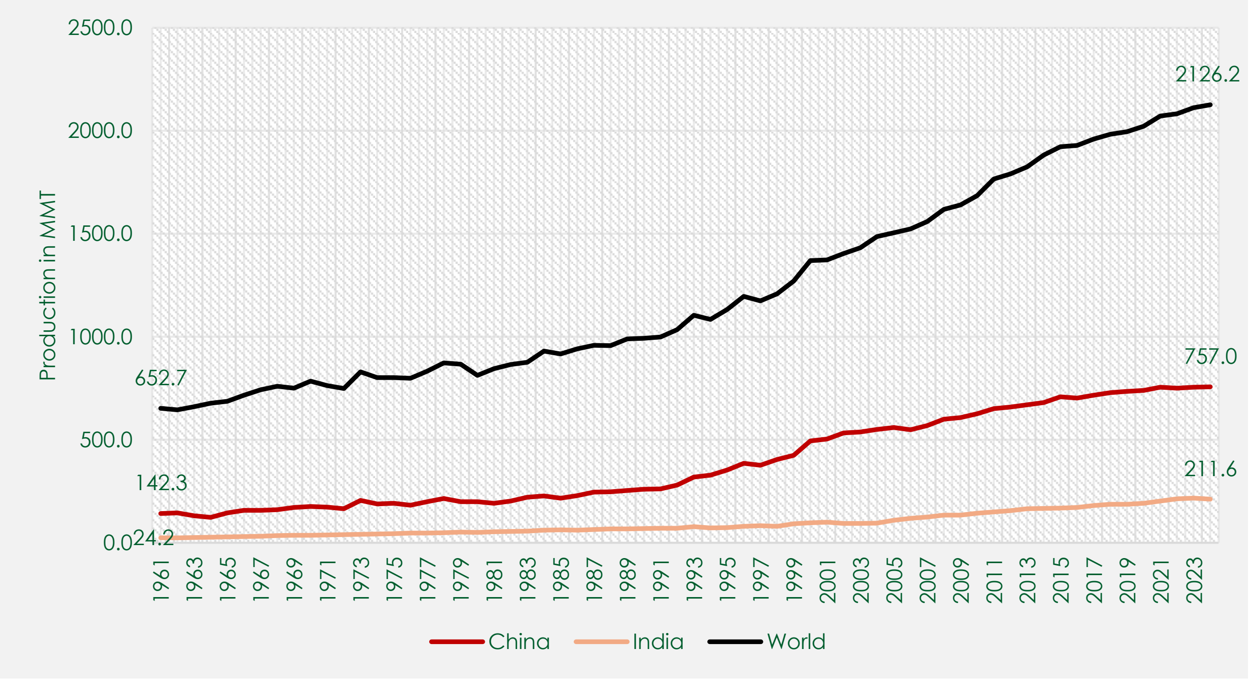
Global vegetable production from 1961 to 2024 underscores a steady increase in worldwide output, with prominent growth trajectories for both China and India (**Figure 1.6**). This rising trend reflects improvements in agricultural productivity and farming techniques, expanding global demand for horticultural products. China displays a sharp rise in vegetable production, particularly from the late 1980s onward. By the early 2000s, China's production exceeds that of all other countries, strengthening its position as the world's top vegetable producer. India also generates a steady upward trend in vegetable production. However, its growth rate is relatively modest compared to China. China has the largest protected horticulture area in the world, accounting for nearly 60 percent of the global protected cultivation area (Tong X et al, 2024). This has contributed substantially in China's progress in the sector. In India on the other hand an area of 2.64 Lakhs ha has been covered under protected cultivation which is 0.13 percent of the net sown area, between 2014 and 2023 (Lok Sabha Question, 2023).

Figure 1.5: Country-wise Share of Total World Vegetable Production, TE 2023-24



Source: Author's calculation using FAO Statistics

Figure 1.6: Production of Vegetables in India and China, 1961-2024[2]



Source: FAO Statistics

[2] It includes roots and tuber crop and other vegetables

The increasing global dependence on vegetable production emphasizes the implication of China's dominance, while India's steady growth proposes that further policy interventions, technological advancements, and infrastructure enhancements could help bridge the gap with leading producers.

1.4 INDIA'S VEGETABLE AND FRUITS PRODUCTION

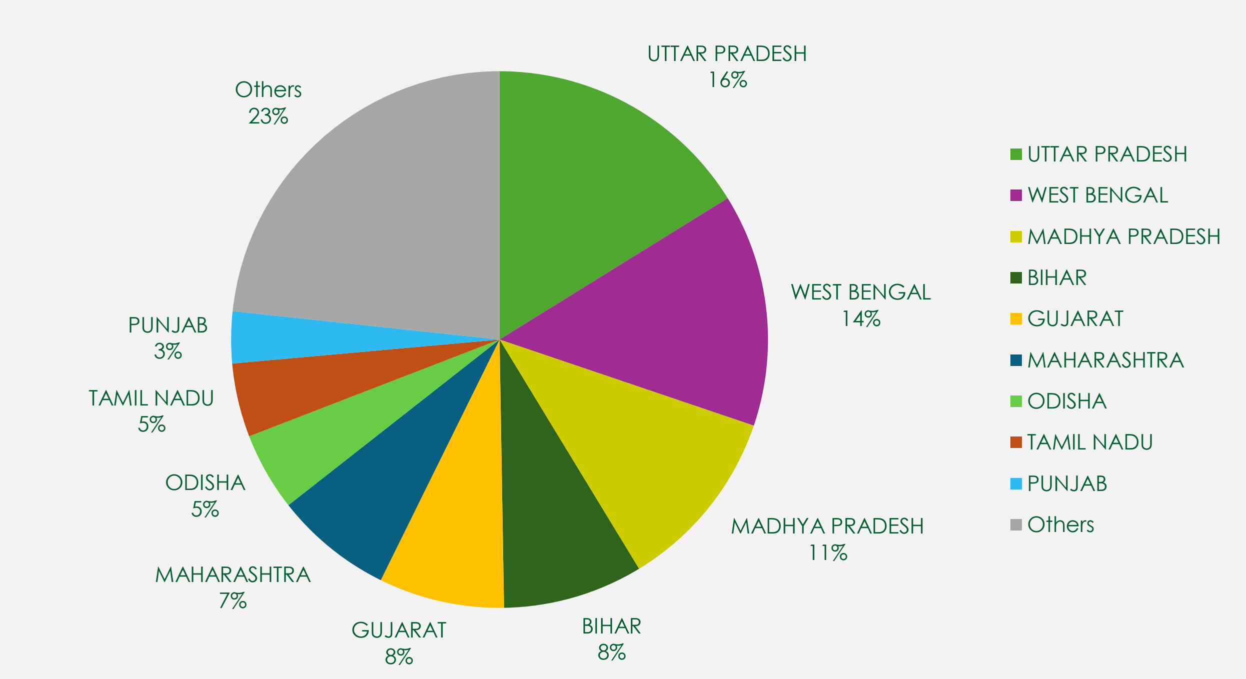
India has observed extraordinary growth in fruit and vegetable production over the past six decades, with noteworthy acceleration post-1990. Government initiatives such as the MIDH have played a vital role in driving this development by improving the availability of better-quality seed varieties, modern farming techniques, and improved market access.

India is a major global producer of bananas, mangoes, papayas, and guavas, contributing over 26 percent of global banana production and nearly 43 percent of the world's mango, guava, and mangosteen output. The country also is the second largest producers of potatoes, tomatoes, and onions, underscoring its significance in global horticulture. However, despite this robust production base, post-harvest losses and supply chain inadequacies continue to hamper the sector's full potential, distressing both domestic availability and export performance.

The foremost fruit and vegetable-producing states in India show considerable variation in production levels, reflecting diverse agro-climatic conditions and regional specialization. State wise analysis highlight a large variation in production level across states. Uttar Pradesh, West Bengal, and Madhya Pradesh together contribute 41 percent of the country's total vegetable production (**Figure 1.7**), with UP is the key producer of potato and bottle gourd and West Bengal is the largest producer of potatoes and leafy greens. Meanwhile, Andhra Pradesh, Maharashtra, and Uttar Pradesh together account for around 40 percent of total fruit output, specializing in crops such as mangoes, bananas, and citrus fruits.

The regional variations in horticultural productivity underscore the need for state-specific policies and localised interventions. For instance, states with higher productivity levels have leveraged irrigation facilities, high quality seeds, and better market linkages, whereas others are struggling with poor quality infrastructure and post-harvest losses. Establishment of cold storages, expanding transportation networks, and encouraging technological adoption can play a noteworthy role in bridging these regional gaps.

Figure 1.7: State-wise Contribution of Vegetables in TE 2023-24



Source: Author's calculation using Horticulture Statistics, Department of Agriculture and Farmers' Welfare, MoA&FW, Government of India (GoI)

India's dominance in global production of fruit is well established. However, attaining the sector's full potential requires organizational reforms and strategic investments. By employing best practices from high-yielding nations, strengthening infrastructure, and take advantage of technological advancements, India can further strengthen its role in the international horticulture sector. Sustainable agricultural growth, better farmers' income, and stable food security will be vital for positive and long-term progress in this domain.

1.5 FROM CROP DIVERSIFICATION TO TECHNOLOGY-INTENSIVE HIGH-VALUE AGRICULTURE

While the previous discussion establishes that India is experiencing a gradual shift towards high value crops-with rising share of horticulture, livestock, and allied activities, in GVO-diversification alone is not adequate to ensure sustained growth and high level of income. The transition from cereals to high value crops represents the first step towards structural transformation. The next step is to improve productivity, stabilise output, and integrate farmers more efficiently in the organized value chain.

In many regions, diversification into horticulture fails to leverage its full potential owing to yield volatility, perishability, weak post-harvest infrastructure, and exposure to climatic erraticism. Although fruits and vegetables generate higher profitability relative to cereals, it is accompanied by higher production and market risks. Small and marginal farmers who constitute nearly 86 percent of farming households often face restrictions in accessing working capital, quality inputs, and favourable marketing channels. Accordingly, diversification without technological upgrading may bring about income volatility rather than resilience (Kumar et al, 2012; Pingali and Rosegrant, 1995).

In this backdrop the shift from area-extensive to technology-intensive high-value agriculture turn out to be critical. As land is scarce and environmental degradation is also increasing at an alarming rate, productivity gains must gradually arise from better input-use efficiency, climate control, and precision farming practices. Protected cultivation through polyhouses, shade nets, and controlled environment systems emerges as one such institutional and technological response (Santosh et al, 2024).

Protected cultivation represents a qualitative shift in the nature of diversification. Unlike traditional area-led expansion into horticulture, it represents yield-led growth driven by micro-climate management, drip irrigation, high yielding seed adoption, and year-round production cycles. It mitigates several structural bottlenecks that have historically restricted the scaling of high-value horticulture in India namely seasonality, quality variation, and vulnerability to climatic shocks.

Thus, the evolution of protected cultivation can be understood not merely as a horticultural innovation but as part of the broader structural transformation of Indian agriculture:

- From subsistence agriculture to commercialization of production
- From cereal dominance to high-value crops
- From area expansion to productivity rise
- From traditional farming to capital-intensive agri-enterprise

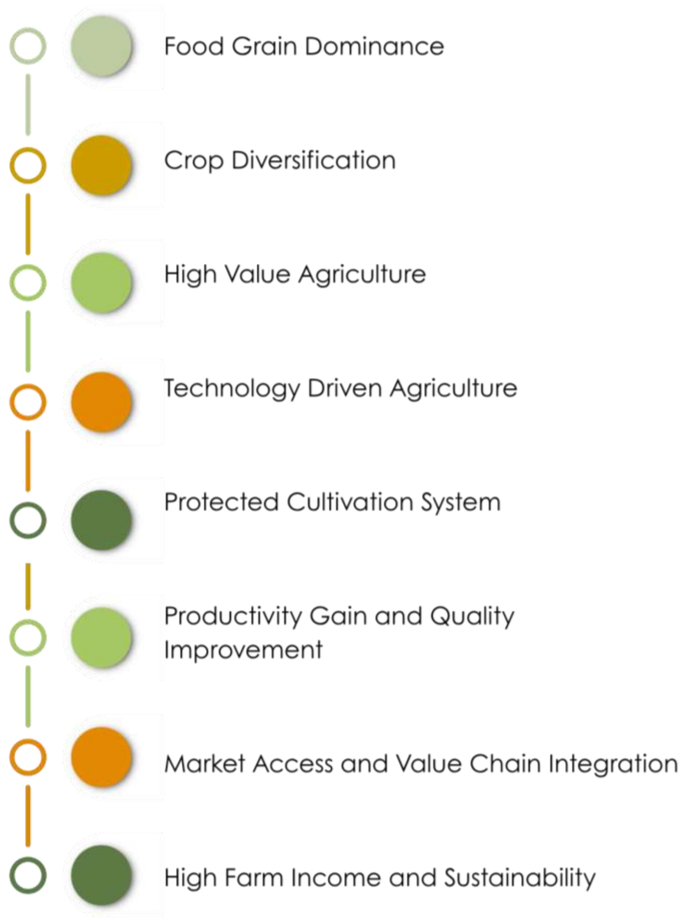
1.6 CONCEPTUAL FRAMEWORK: LINKING CROP DIVERSIFICATION, PROTECTED CULTIVATION AND FARM INCOME

The evolution of agricultural systems toward higher productivity and improved farm income necessitates a blend of structural, technological, and market-oriented changes. In the backdrop of Indian agriculture, where small and marginal farmers constitute the majority of farming households and availability of land is also limited, diversification into high-value crops has emerged as a key strategy for income augmentation. The productivity and profitability of high-value crops are often controlled by climatic variability, pest attacks, and market volatility. In this context, technological innovations such as protected cultivation play a crucial role in allowing farmers to realize the full potential of diversification.

Crop diversification is the shift from traditional monoculture or cereal-dominated systems toward a larger mix of crops, including fruits, vegetables and other high-value commodities. This transition is impacted by various factors, including changing dietary pattern, urbanization, increasing income, and finding a niche in the market demand for horticultural products. Diversification lets farmers to allocate land and resources to crops that offer higher economic returns and better employment prospects. It also helps diminish production risks by distributing them across different crops and enterprises.

Even with these advantages, farmers cultivating horticulture crops are often exposed to new forms of risks. Fruits and vegetables are perishable in nature and more reactive to climatic conditions than cereals. Yield fluctuations instigated by erratic temperature, pest infestations, or irregular rainfall can considerably affect farmers' income. Moreover, horticultural crops need more comprehensive management and higher-quality inputs, which may upsurge production costs and financial burden for farmers. Therefore, diversification must go hand in hand with technological interventions that stabilize production and improve resource-use efficiency.

Figure 1.8: Structural Transformation of Indian Agriculture



Protected Cultivation represents a form of technological intervention that eases the evolution of high-value agriculture. Protected cultivation is a high-tech agricultural technique that deploys a microclimate controlling temperature, humidity, light, to fashion optimal growing conditions, enabling year-round production of high-value crops. Using structures like polyhouses, greenhouses, and net houses, it guarantees uniform quality and yields while shielding plants from pests, diseases, and adverse weather conditions, and reduces water and chemical use.

Protected cultivation can be seen as an instrument that alters area-based expansion of horticulture into yield-driven growth. While diversification increases the share of high-value crops in total agricultural output, protected cultivation also ensures economic feasibility. As it enables higher yield than open field and year-round production, farmers' produce can fetch better return during off-seasons. In addition to higher yield, protected cultivation improves the physical quality of harvest, permitting farmers to access premium markets and organized retail chains.

Another significant dimension of the theoretical framework is market integration. High-value crops produced under protected cultivation are often targeted toward urban markets, supermarkets, and food processing industries. The capacity to produce uniform and high-quality vegetables throughout the year permits farmers to start a strong connection with wholesalers, institutional buyers, and retail supply chains. Improved market integration not only result in better price realization but also moderates the uncertainty related with seasonal price fluctuations.

From an income standpoint, the joint effects of diversification and technological adoption generate manifold economic benefits. First, higher productivity and improved crop quality increase gross farm revenue. Second, improved resource-use efficiency predominantly in terms of water and fertilizer use ensures sustainability over time. Third, the ability to cultivate crops during off-season periods permits farmers to capture higher market prices, thereby increasing profitability. These factors collectively subscribe to higher farm income and improved livelihood security.

The theoretical relationship between crop diversification, protected cultivation, and farm income can therefore be explained as a chronological process (**Figure *1.8***). Primarily, farmers diversify their cropping patterns by shifting from cereal-based systems to high-value horticultural crops. In the following stage, technological innovations such as protected cultivation improve productivity, stabilize yields, and enhance input-use efficiency. Finally, better productivity and market integration decipher into higher and more stable farm income.

This framework also features the role of government policy provision in aiding this transformation. Government programmes such as the MIDH provide financial assistance for building protected structures, adopting micro-irrigation systems, accessing improved planting material, allocate improved quality of seeds and organise training programmes for farmers and extension service providers. Research initiatives further help farmers find the technical knowledge vital to make protected cultivation systems successful.

At a larger context, the adoption of protected cultivation echoes a shift toward a more intensive and technology-driven agricultural model. As land resources are more and more scarce and environmental pressures deepen, future agricultural growth will rely less on scaling up cultivated area and more on enhancements in productivity and resource efficacy. Protected cultivation, hence, signifies a vital roadmap for accomplishing sustainable agricultural intensification while simultaneously augmenting farmers' income.

In summary, the theoretical framework established in this study places protected cultivation as a crucial intermediary between crop diversification and income growth. Diversification offers the structural basis for shifting toward high-value agriculture, while protected cultivation enables farmers to exploit the productivity and profitability of those crops. Together, these developments contribute to the larger transformation of Indian agriculture toward a more resilient, market-oriented, and income-enhancing production system.

2 METHODOLOGY

METHODOLOGY

This study presents a comparative analysis of three cases of coloured capsicum cultivation under protected systems in Haryana and Uttar Pradesh. Haryana, located in the Indo-Gangetic plains and supplying straight to the NCR, aids from proximity to finest wholesale and institutional markets. Uttar Pradesh, by contrast, embodies an emerging peri-urban horticultural cluster where young agripreneurs are leveraging digital retail platforms, modern input supply chains, and government subsidy programs to scale up protected cultivation. Studying these cases lets us recognize how market linkages, investment structures, and environmental management practices outline profitability and risk across different production ecologies.

The study adopts a mixed-method approach combining financial appraisal, risk analysis, and field based economic analysis to evaluate the viability of protected cultivation, particularly polyhouse and shade net-based capsicum production. The methodology integrates cost-benefit analysis, discounted cash flow techniques, and stochastic simulation model to capture both profitability and uncertainty associated with high-value agriculture.

A detailed budgeting approach is used to estimate initial capital investment (polyhouse structure, drip irrigation, planting material etc), operating costs (labour, fertilizer, pesticides, maintenance, electricity), and revenue streams (based on crop yield and market price of capsicum). To ensure a robust financial assessment, profitability has been estimated by adjusting for annualized fixed costs, providing a more comprehensive view of long-term economic viability. Furthermore, the study incorporates a structural debt analysis by calculating the Equated Monthly Instalment (EMI) and comparing the average return during the loan tenure against the projected returns following full debt repayment.

The standard formula for calculating the EMI is

$$\text{EMI} = P \times r \times \frac{(1+r)^n}{(1+r)^n - 1}$$

P: The Principal amount (the loan amount)

r: The monthly interest rate

n=Loan tenure in months

The annual net cash flow is computed as:

$$Net\ Cash\ Flow_t = Total\ Revenue_t - Total\ Cost_t \text{..........(i)}$$

The **Net Present Value (NPV)** method is used to assess the long-term profitability of investment in protected cultivation by discounting future cash flows.

$$\text{NPV} = \sum_{t=0}^{T} {R_t - C_t}/{(1+r)^t} \text{.................(ii)}$$

Where:

R_t = Revenue in year *t* r = Discount rate (cost of capital)

C_t = Cost in year *t* T = Project life

In the context of protected cultivation, a positive NPV indicates that high initial capital costs are compensated by higher long-term returns, especially due to off-season production and premium pricing.

The IRR is the discount rate at which the NPV becomes zero. It reflects the expected rate of return on investment.

A deterministic sensitivity analysis is conducted by varying key parameters like yield and output price. This helps identify critical variables influencing profitability.

To incorporate uncertainty and assess the risk associated with protected cultivation, the study undertakes Monte Carlo simulation as a stochastic modelling technique. Unlike deterministic approaches that depend on fixed values of main variables, Monte Carlo simulation permits variability in critical parameters such as yield, output prices, and input costs, which are fundamentally ambiguous in horticultural production systems. In this approach, probability distributions are allocated to these variables based on observed data and reasonable assumptions. For instance, yield may fluctuate due to climatic conditions and management practices, while market prices fluctuate depending on demand-supply dynamics.

$$IRR_i = f(P_i, Y_i) \text{.........(iii)}$$

P_i= price at ith iteration Y_i= yield at ith iteration

where each variable is randomly drawn from its respective probability distribution in the i^{th} simulation. The simulation process involves generating a large number of such iterations (i=1,2,…,N) producing a distribution of IRR values: $\{IRR_{1,} IRR_{2,}……..,$ $IRR_{N,}\}$

This allows the estimation of the expected return and associated risk:

$$E(IRR) = 1/N \sum_{i=1}^{N} IRR_i \text{……….(iv)}$$

By adopting cost-return analysis, investment viability metrics, and qualitative field insights, the study highlights both the potential and constraints of protected capsicum cultivation.

Primary data for the study has been collected through interviews, focus group discussions, and consultations with key stakeholders, including government officials. The field surveys generated quantitative information on parameters such as income per hectare per production cycle, capital and working capital requirements, incidence of crop failure, payback period of investments, and employment generation.

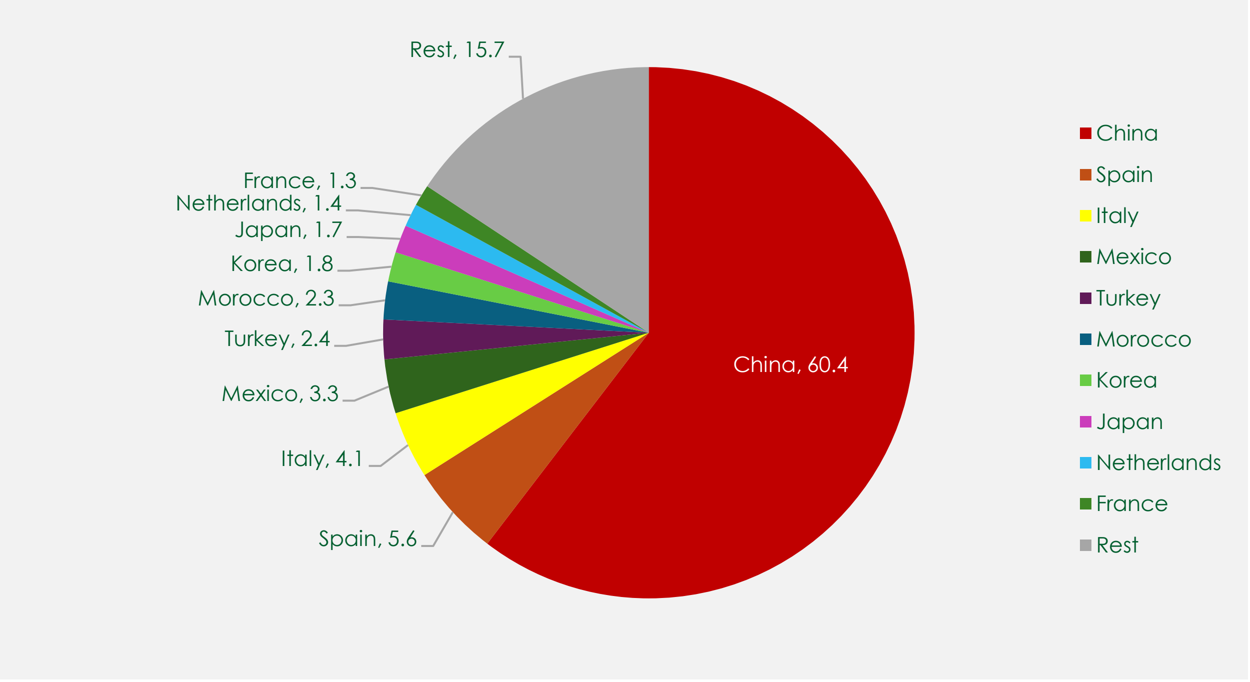
The following section situates India's horticultural expansion within this global and national transformation and examines how protected systems are redefining productivity, profitability, and risk in high-value vegetable production, with a particular focus on capsicum as a representative crop.

3 GLOBAL LANDSCAPE OF PROTECTED CULTIVATION

GLOBAL LANDSCAPE OF PROTECTED CULTIVATION

Recent satellite-based assessment data indicates that there has been considerable expansion in protected cultivation over the past decades. Study estimates that greenhouses currently occupy 1.3 million ha of land worldwide across 119 countries, increased from a very small area of 30,000 ha four decades ago. The top ten countries account for 84.3 percent of the global share of greenhouse coverage, including China (60.4 percent), Spain (5.6 percent), Italy (4.1 percent), Mexico (3.3 percent), Turkey (2.4 percent), Morocco (2.3 percent), the Republic of Korea (1.8 percent), Japan (1.7 percent), the Netherlands (1.4 percent) and France (1.3 percent) (**Figure 3.1**, Tong X et al, 2024).

Figure 3.1: Country-wise Area under Protected Cultivation



Source: Tong X et al, 2024, NASA 2024

3.1 GLOBAL EXPERIENCE OF PROTECTED CULTIVATION

CHINA

China is the most important role model of large-scale expansion in protected cultivation in horticulture; accounting for nearly 60 percent of global coverage. These structures are distributed across diverse agro-climatic zones of China. However, the spatial concentration is pronounced in the extensive alluvial plain of Northern China. The most significant cluster of greenhouses both within China and globally is located in Weifang, a prefecture-level city in Shandong Province in northeastern China. This cluster alone extends over approximately 820 square kilometers, illustrating the scale and geographic concentration of protected cultivation within this region (Tong X et al, 2024). The revolution in protected cultivation in China was motivated by a mix of technological adaptation, positive policy environment, and growing demand for vegetables especially in the cold winter months. The literature suggests that adoption of protected cultivation in China started evolving gradually and reached momentum after the mid-20th century. While in the initial stage temperature control in horticulture was done through basic natural heating method and enclosure systems, the modern development of protected cultivation started after 1949, when perennial vegetable production for food security drive was a nationwide priority. The demand for fresh vegetables became even more intensified owing to rapid urbanization and population growth. This demand-side push shaped the trajectory of technological innovation.

A technological revolution happened with the beginning of plastic films in late 1950s. This was followed by the construction of bamboo-wood structured plastic greenhouses. The widespread use of polyethylene films in the 1980s dramatically reduced the initial capital cost of greenhouses, allowing extensive adoption of plastic arch sheds. The vegetable basket project was launched in 1980s to promote vegetable production and supply management. This initiative further promoted protected cultivation as a strategic roadmap for China's agri-food system. Unlike the high-cost European models, China concentrated on cost-effective and energy efficient designs suitable for small scale farming households (Ma, X et al, 2023).

One of China's most significant technological innovations has been the establishment of the solar greenhouse with a north wall[3], first built in Shouguang in

[3] A solar greenhouse with a north wall is generally oriented in an east–west direction in the northern hemisphere and is designed to enhance energy efficiency through passive solar heating. In this structure, the north wall is opaque, insulated, and constructed with thermally massive materials that absorb and store heat during the day and release it at night, thereby reducing heat loss during winter. The south-facing side is

1989. The innovation has resulted in substantial reduction of dependence on fossil fuels that in turn reduced operating costs, enabling widespread adoption across northern China. This design is identified as a distinctive, context specific innovation that led to balanced yield with energy efficiency.

Since 1990s, various technological innovations have been adopted including multi-span greenhouses, shading systems, moisture regulation, and so on. However, the Chinese model is characterised by a dual structure of extensive low-cost solar run greenhouses coexisting with more capital-intensive glass house structures. It promoted scaling up with affordability on one hand and technical expansion on the other.

Overall, literature suggests that China's success is attributed to technological advancement, strong policy support, rapid material innovation, and growing market in the urban areas (Tong X et al, 2024, NASA 2024, Ma, X et al, 2023).

ISRAEL

Israel has approximately 410,000 hectares of agriculturally suitable land, primarily concentrated in the central, northern, and northern Negev regions, although not all of it is cultivated each year due to crop cycles and orchard renewal. About half of this land is devoted to field crops, one-quarter to orchards, and the remainder to vegetables and flowers, with orchards mainly in the north and centre and field crops in the Negev and Amakim regions. Despite most agriculture being open-field, around 15,000 hectares are under protected cultivation systems such as greenhouses, tunnels, and net-houses (Ministry of Agriculture and Food Security, Israel).

Protected cultivation technologies in Israel represent a highly advanced and integrated agricultural system characterized by precision, resource efficiency, and intensive management of crop environments. Israeli greenhouses are designed to create optimal growing conditions through the use of climate control systems, fertigation, and automated irrigation, enabling year-round production with high yields and quality. The adoption of soilless cultivation techniques such as hydroponics, along with recirculated irrigation systems, ensures efficient use of water and nutrients critical in a water-scarce environment. Advanced technologies including LED lighting, sensors, and computer-based monitoring allow real-time

covered with transparent glazing to allow maximum sunlight penetration, while the insulated north wall reflects light back into the greenhouse and helps maintain stable internal temperatures. This design often enables year-round cultivation without the need for active heating systems (He, M. et al, 2025) adjustments to temperature, humidity, and nutrient delivery, enhancing productivity and reducing resource wastage. Additionally, innovations such as dehumidification systems and robotics further improve energy efficiency and operational precision . Overall, Israel's protected cultivation model demonstrates how technological integration and precision agriculture can significantly enhance crop productivity, sustainability, and resilience under constrained natural resource conditions (https://israelagri.com).

Protected cultivation technologies in Israel are complemented by a range of practical case studies that demonstrate their effectiveness in enhancing productivity, resource efficiency, and sustainability. For instance, a case study on pineapple cultivation in greenhouses highlights the use of an electric sprayer system that significantly improves spraying efficiency and reduces labour requirements, showcasing the role of mechanization in intensive horticulture (Maor et al, 2023) . Another example is the adoption of specialized fertigation practices in greenhouse systems, where precise nutrient delivery through recirculated irrigation enables higher yields while minimizing water and fertilizer losses (Golovaty, 2023). Similarly, innovations such as DryGair dehumidification technology illustrate how humidity control can reduce energy consumption and disease incidence, thereby improving overall crop performance (Meir, R, 2023).

Collectively, these case studies underline how Israel's integrated approach combining engineering, digital technologies, and agronomic precision has successfully transformed protected cultivation into a high-productivity and resource-efficient agricultural model.

SOUTHERN EUROPE: EXPORT ORIENTED INTENSIFICATION

Southern Europe, particularly Spain and Italy, represent one of the most prominent regions of protected cultivation after China. Spain's Almería region is one of the major protected cultivation clusters globally, characterised by plastic covered greenhouses designed for intensive vegetable production targeted for European export market. These systems are predominantly clustered in semi-arid zones intending to mitigate water scarcity and stabilize yield.

Italy also holds a substantial share in global coverage (4.1 percent) specializing on vegetables and ornamental crops. Mediterranean countries largely focus on vegetable crops like tomato, cucumber, peppers, exploiting the benefits of protected cultivation in mitigating environmental risks and leveraging seasonal advantages (Tüzel, Y & Katsoulas, N; 2017).

THE NETHERLANDS: TECHNOLOGY DRIVEN ENERGY INTENSIVE MODEL

In contrast to plastic covered low cost structure, the Netherlands characterizes a high-technology, glasshouse based model of protected cultivation. The structure includes features like glass covered multi-span structures, modern temperature control mechanism, co-generation units, CO_2 enrichment for increases photosynthetic efficiency, hydroponic and semi-hydroponic production and so on. Integrated pest management and biological control. Although area coverage is smaller compared to China, it is one of the World's largest exporter of horticultural products. The Netherlands' success rests less on area expansion and more on yield, technological innovation, and integration of research, extension, and export logistics (Nass, T; 2010).

NORTH AMERICA: AGGLOMERATION IN THE SEMI-ARID AREAS

The USA accounts for a very small share of global coverage. As per horticulture census data of USA for the latest year 2019, greenhouse, shade structure, and natural net account for around 450 ha area. It has mostly come up in the peri-urban and semi-arid states like California and Oregon. Mexico however emerged as a more dynamic player in Northern America constituting around 3.3 percent of global coverageThe adoption of technology started in the 1990s but expansion has taken place since early 2009 following the launch of the Strategic Project for Protected Agriculture under Mexico's National Development Plan. Mexican protected cultivation is mostly export oriented supplying to the USA during winter months. The annual growth rate of protected area during the period of 2000 and 2019 is estimated to be 31.7 percent, making it one of the most dynamic sectors of Mexican agriculture. Geographically, protected cultivation is highly concentrated. Nearly 57 percent of total protected area is located in three states Sinaloa (20 percent), Jalisco (20 percent), and Michoacán (17 percent). In 2019, 96.5 percent of protected area was devoted to fruits and vegetables, while only 3.5 percent was used for floriculture. Tomatoes remain the dominant crop followed by peppers, strawberries, raspberries, cucumbers, and blueberries. Government policies have played a major role in expansion of protected cultivation. Government disbursed subsidies up to 50 percent of project costs, with significant financial allocations between 2001 and 2018 to support infrastructure and adoption. These policy interventions, combined with strong North American demand and competitive labour costs, have fast-tracked the diffusion of protected cultivation technologies (Wu, F et al; 2022, Victoria, NG et al, 2011).

Other countries that have significant presence of protected cultivation include Turkey, Morocco, South Korea, and Japan. In these regions there is dominance of climate adaptive greenhouse system aiming at risk mitigation strategy against extreme weather condition and water scarcity. Protected cultivation in South Korea is largely characterized by widespread use of low-technology plastic greenhouses, with steady but prominent expansion of high-technology glasshouse systems. Major greenhouse crops include watermelon, strawberry, tomato, cucumber, fresh pepper and paprika, with paprika evolving as a key export commodity, particularly to Japan. Historically, Korea's greenhouse expansion was motivated by the "white revolution" of plastic greenhouses in the 1980s and government-supported glasshouse programs in the 1990s. Since 2018, policy emphasis on "smart farming" and the adoption of Smart Farm Innovation Valleys initiative signal a renewed push toward technologically advanced, export-oriented horticulture (Ministry of Foreign Affairs, South Korea; Food and Agricultural Organization). Overall in South Korea, there exists a dual structure of protected cultivation- low cost platic system coexisting with steadily growing high-tech system. The adoption of protected cultivation has been governed by export demand and state-led modernization efforts. Japan on the other hand, is experiencing structural transformation motivated by corporatization, technological modernization, and policy-led advancement of smart agriculture. Since the amendment of the Cropland Act in 2009, which enabled broader corporate participation through lease schemes, the number of agricultural corporations qualified to own cropland increased significantly, reflecting a shift toward scale expansion and commercialized greenhouse operations. Currently, horticulture in greenhouse provides almost 100 times more income compared to paddy cultivation in Japan. The "next-generation greenhouse horticulture model" endorsed since 2013 underscores extensive, technologically cutting-edge facilities integrating climate control, biomass boilers, geothermal energy, and data-driven management systems (Ode, Y, 2020).

4 INDIA'S PROTECTED CULTIVATION LANDSCAPE

INDIA'S PROTECTED CULTIVATION LANDSCAPE

Agriculture in India is also undergoing structural transformation through technological innovation with an increasing focus on high-value horticulture. Unlike European and Asian countries, India's tropical climate allows for year-round production of a diversified crop basket. However, climatic shocks like unseasonal rain, drought, pest attacks, deteriorating soil quality etc hampers horticulture crops severely. Protected cultivation-through polyhouses, shade nets, poly tunnels- offers a feasible solution to challenges like these (Kumar et al, 2021) (**Figure 4.1**). However, widespread adoption remains inadequate, particularly among small and marginal farmers, due to high initial private investment and technical complexity (NHB, 2023). A study by Ansary et al (2019) in West Bengal highlighted that capsicum plants under polyhouse displayed higher fruit weight, larger fruit diameter, and considerably better yields than those grown in open fields. With application of growth hormones like Planofix, yield reached 39.4 tonnes/ha in polyhouses versus 28.2 tonnes/ha in open field, indicating nearly 40 percent hike in productivity.

Studies like Ngullie and Biswas (2016), Singh and Solanki (2014), conforms to the findings that, polyhouses create a favourable environment (optimal temperature, moisture level, filtered light) that supports better photosynthesis, and reduced flower drop. In open field cultivation productivity is highly sensitive to temperature variability, erratic rainfall, and pest attacks.

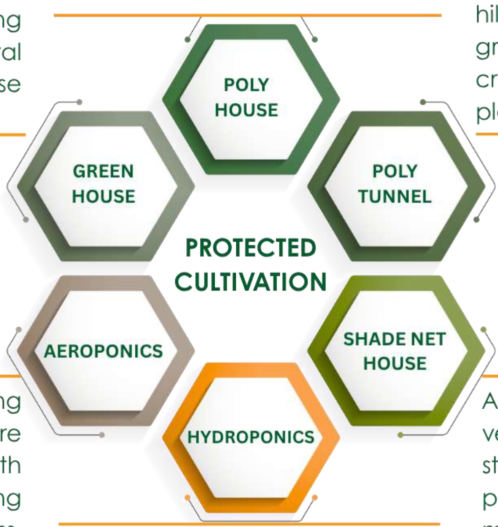
Horticulture crops cultivated in protected environment have better physical quality than produced in open field. Fruits grown in polyhouses are more uniform in size, texture, colouration due to low abiotic pressure and better nutrient uptake (Singh et al, 2016). Open field output is characterised by uneven quality, hence fetches lower price, making it less competitive in high-value retail chains and export markets. Protected cultivation provides a physical barrier against many insects and viral pathogens, contributing to lower pesticide use (Singh et al, 2003). This leads to lower cost of cultivation and a sustainable agricultural practice. On the contrary, open field system exposes crops to uncontrolled pest attacks, requiring more chemical application resulting in potential environmental hazards.

Figure 4.1: Types of Protected Cultivation Technologies

A greenhouse is a fully climate-controlled structure equipped with heating, cooling, and automated systems-often using double-walled polycarbonate sheets-designed for cultivating exotic and of-season vegetables, floriculture crops, planting material, and varietal improvement under adverse agro-climatic conditions.

A polyhouse is a simpler, naturally ventilated version of a fully climate-controlled greenhouse, used for cultivating exotic and off-season vegetables, floriculture crops, and planting material under favourable agro-climatic conditions.

A poly tunnel is a naturally ventilated, climate-moderated structure made of pre-galvanized tubes, used mainly in hilly and temperate regions for growing vegetables, floriculture crops, and acclimatizing planting material.



Aeroponics is a soilless growing method where plant roots are suspended in air and misted with nutrient-rich droplets, enabling faster growth, full CO_2 access, and reduced disease transmission compared to soil or hydroponics.

Hydroponics is a soilless cultivation system where plants grow in nutrient-rich water with controlled pH and oxygen levels, enabling efficient nutrient use, higher productivity, and reduced pest and disease incidence.

A net house is a naturally ventilated, climate-moderated structure made of galvanized pipes, wood, or bamboo, used mainly in low-rainfall regions for growing vegetables, floriculture, and nursery plants.

Protected cultivation requires higher initial capital cost for establishment of the structure and future operation. The extensive adoption is dependent on the availability of government support. With government support covering 30-50 percent of the establishment cost, the payback period reduces from 3.5 years to nearly 1.5 years (Prakash et al, 2021). The high upfront cost discourages smallholders, who presently constitute 86 percent of Indian farmers.

Despite clear positive returns, the adoption of protected cultivation is limited in India compared to countries like the Netherlands or Israel (Pachiyappan et al, 2022). Constraints include high capital costs and reliance on subsidies, lack of technical know-how among smallholders; marketing bottlenecks and reliance on aggregators, which reduce producers' share in consumer price. Climatic adaptation challenges, as polyhouse management necessitates precise irrigation, fertigation, and temperature regulation.

Over the past two decades, the Government of India has implemented quite a few centrally sponsored schemes that offer financial assistance, infrastructure, technology dissemination, and market support. A major component of these schemes is the advancement of protected cultivation, which permits the production of high-value horticultural crops under controlled environments.

4.1 MAJOR GOVERNMENT PROGRAMMES FOR HORTICULTURE DEVELOPMENT

MIDH is an umbrella scheme that integrates several horticulture initiatives. It includes sub-missions and boards like National Horticulture Mission (NHM), Horticulture Mission for North East & Himalayan States (HMNEH), National Horticulture Board (NHB), Coconut Development Board (CDB), and Central Institute for Horticulture (CIH). It covers fruits, vegetables, root and tuber crops, mushrooms, spices, flowers, aromatic plants, coconut, cashew, cocoa and bamboo through various interventions.

Under MIDH, aid is provided for various components of protected cultivation. These include greenhouse structures, shade net houses, walk-in tunnels, plastic tunnels, anti-bird and anti-hail nets, and plastic mulching. Provisions are given for selecting a variety of construction materials of greenhouses and shade net houses. The cost is inclusive of irrigation systems. Preferences are given if farmers use locally available material to minimize cost of construction of such structures. However, for availing subsidy assistance, all material/ technologies should conform to BIS standards. New components like Hydroponics and Aeroponics, Soil Replacement, Sensor Based Automation System for fertigation, Solar Fencing, Weed Mat, etc. are promoted under the Mission. For fan-and-pad and naturally ventilated tubular greenhouse systems, the scheme offers assistance at 50 percent of the total cost, subject to a maximum area of 4000 square metres (sq.m) per beneficiary. In the case of wooden and bamboo greenhouse structures, financial support is also given at 50 percent of the cost, limited to 20 units per beneficiary, with each unit not exceeding 200 sq.m (**Table 4.1**). Similarly, support is available for shade net houses, walk-in tunnels with assistance of 50 percent of the permissible cost for up to 1000 sq.m. per beneficiary and plastic tunnels up to 1000 sq.m per beneficiary. For protective installations such as anti-bird or anti-hail nets, assistance is provided at 50 percent of the cost for a maximum area of 5000 sq. m., while plastic mulching is supported at 50 percent of the cost up to an area of 2 hectares. In addition to MIDH, support for protected cultivation is also extended through other government schemes such as the Rashtriya Krishi Vikas Yojana (RKVY) and the National Mission for Sustainable Agriculture (NMSA), which intend to encourage the adoption of climate-resilient and resource-efficient agricultural practices.

Capacity building formula is an important component of MIDH. Under its Human Resource Development (HRD) programme, training is organized for farmers, agripreneurs, field-level extension workers and government officials on various characteristics of horticulture, including the management and functioning of polyhouses and other protected cultivation technologies. To further reinforce technical support, 22 Precision Farming Development Centres (PFDCs) have been established across the country. These centres focus on regulating precision farming techniques, promoting the use of plasticulture technologies, and establishing training and awareness programmes for stakeholders. In addition, farmers are given access to technical literature and information regarding available financial assistance under the scheme in local languages to ease wider adoption of protected cultivation technologies.

Table 4.1: Government Schemes for Protected Cultivation under MIDH

Component	Pattern of Assistance	Maximum Area per Beneficiary
Greenhouse Structure	50 percent of maximum permissible cost	4000 sq. m
Shade Net House	50 percent of maximum permissible cost	4000 sq. m.
Walk in Tunnel	50 percent of maximum permissible cost	4000 sq. m
Plastic Tunnel	50 percent of maximum permissible cost	1000 sq. m
Anti Bird/Anti Hail Nets	50 percent of maximum permissible cost	5000 sq. m
Plastic Mulching	50 percent of maximum permissible cost	2 ha

Source: PIB 10th February, 2023

CoEs under the MIDH are dedicated hubs established to demonstrate, train, and disseminate high-tech agricultural technologies, with 52 approved nationwide (36 completed and 16 under process). In collaboration with partners like Israel and Netherlands, they focus on enhancing productivity, quality planting materials, and sustainable farming practices for fruits, vegetables, and flowers. The CoE programme, initiated in 2012 through a bilateral collaboration between the Dutch and Indian governments, emphases on strengthening Indian agriculture through technical support, capacity building, and improved production standards. Farmers gain practical skills in crops such as onions, potatoes, greenhouse vegetables and flowers, fruits, enhancing both productivity and resilience. The Indo-Israel CoEs assist as advanced agricultural hubs for transferring Israeli agri-technologies adapted to local Indian conditions, with a focus on key crops and intensive farming practices. These centres integrate nursery management, best cultivation practices, protected cultivation, efficient irrigation and fertigation systems to enhance productivity and resource use efficiency. Under this initiative, a total investment of Rs. 5 billion has been incurred (**Table 4.2**). Every year, these COEs produce more than 25 million quality vegetable seedlings, more than 387 thousand quality fruit plants and train more than 1.2 lakhs farmers about latest technology in the field of horticulture (PIB, 2021).

Table 4.2: State-wise Project Cost under Centres of Excellence (Rs. in lakh)

	Dutch Collaboration	Israel Collaboration
Andhra Pradesh		1998
Assam		1034
Bihar		1700
Goa		1179
Gujarat		2050
Haryana		5788
Himachal Pradesh		1904
Jammu & Kashmir	2700	
Karnataka		1100
Kerala	1471	

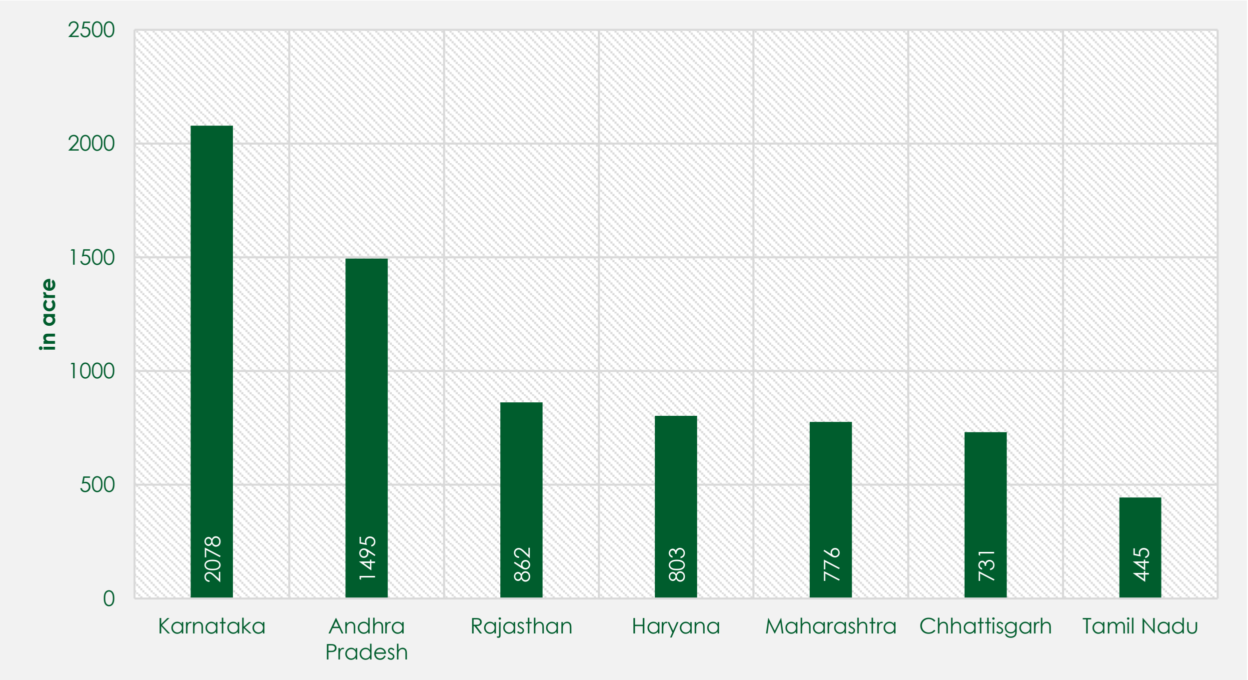
	Dutch Collaboration	Israel Collaboration
Madhya Pradesh		3192
Maharashtra	2573	2300
Meghalaya		1013
Mizoram		950
Odisha		1257
Punjab	1977	3750
Rajasthan		1650
Tamil Nadu		2100
Telangana		1000
Tripura	1000	1918
Uttar Pradesh		3127
West Bengal		1427
Total	**9721**	**40438**

Source: midh.gov.in

4.2 PROTECTED CULTIVATION EXPERIENCE IN DIFFERENT STATES OF INDIA

As discussed in the previous section, over the last two decades, the Government of India and state governments have actively promoted protected cultivation through programmes. As a result, the area under protected cultivation has slowly expanded across several states. Although adoption levels vary depending on agro-climatic conditions, market infrastructure, and institutional support, several states such as Andhra Pradesh, Karnataka, Chhattisgarh, Gujarat, Rajasthan, and Haryana have emerged as important centres of protected cultivation in India in the recent years. (**Figure 4.2**).

Figure 4.2: State-wise Area under Protected Cultivation in Major States under MIDH, 2020-2025



Source: Lok Sabha Unstarred Question No. 3958, 17th March, 2026

Karnataka is one of the foremost states in India in the adoption of protected cultivation, predominantly for high-value vegetable crops such as capsicum, cucumber, tomato, and exotic vegetables. The state's favourable agro-climatic conditions, sophisticated horticulture sector, and access to key urban markets such as Bengaluru have enabled the fast expansion of protected cultivation technologies.

Several districts such as Kolar, Chikkaballapura, and Belgaum have emerged as important centres for polyhouse vegetable cultivation. Capsicum crop owing to its market demand and high return, has gained popularity among farmers. Studies conducted in Kolar and Chikkaballapura districts show that farmers generally have a positive attitude towards adoption of protected cultivation owing to its capacity to augment productivity, better crop quality, and improved profitability. Even though currently the production mainly caters to the domestic demand, higher productivity through protected cultivation creates new potential for export.

In Karnataka, government support in the form of subsidies, technical direction, distribution of hybrid seeds and planting materials have noteworthy role to play in augmenting farmers' income. Around 10,000 polyhouses dedicated to the production of vegetables and flowers have already been constructed in Karnataka.

Protected cultivation in Andhra Pradesh is a key part of horticulture development under MIDH, promoting high-value crops through polyhouses and shade net houses. Farmers receive about 50 percent subsidy for crops like flowers and vegetables, reducing initial investment barriers. The state has expanded significantly, with around 45,916 hectares under protected cultivation (2014–2024), supported by infrastructure, training, and post-harvest facilities. Overall, it supports higher productivity, better quality produce, and increased farmers' income.

Unlike Karnataka, farmers in states like Punjab, Haryana, and Uttar Pradesh were relying on traditional cereal crops for their livelihood until very recently. However, agriculture in these states were plagued by challenges like stagnating profitability, dependence on government procurement system, and environmental hazards, particularly the depletion of groundwater resources from paddy cultivation. These issues have forced farmers to think out of the box. Protected cultivation offers a lucrative roadmap for agricultural diversification in these states by empowering farmers to produce horticulture crops in a risk-free environment insulated from climate variability and pest attacks and ensuring better income. The technology enables farmers to realize higher productivity per unit area, enhance crop quality, and year-round or off-season production, thereby augmenting farm income. Accordingly, the adoption of protected cultivation in these states has the possibility to contribute both to income augmentation for farmers and to the transition toward more sustainable agricultural production systems.

THE CASE OF HARYANA

Haryana has emerged as another important state in the promotion of protected cultivation, particularly for vegetables and flowers. The state's proximity to large urban consumption centres such as Delhi and the NCR offers a robust market for high-value horticultural items produced under protected conditions.

Haryana has different systems of protected cultivation including naturally ventilated polyhouses, net houses, plastic tunnels and so on. Farmers produce vegetables like tomato, capsicum, cucumber, and leafy greens throughout the year, thereby guaranteeing a steady supply of fresh vegetable crops for urban market (Haryana Kisan Ayog).

Government of Haryana has been proactive in promoting protected cultivation among farmers through various initiatives including subsidies for greenhouse construction, training programmes for farmers, and demonstration projects (**Table 4.3**). The establishment of Centres of Excellence under the Indo-Israel Agricultural Cooperation Programme has played a major role in providing these services efficiently.

Field level studies conducted in Haryana confirmed that protected cultivation augment farm productivity and income. For instance, Kumar et al, 2016 shows that tomato cultivation under the polyhouse condition were 54 percent higher than the yield attained in open field cultivation. Although the cost of cultivation under polyhouses was higher, the gross and net returns were also considerably higher due to higher yield and improved market prices.

In the backdrop of declining profit from traditional crops and increasing environmental hazards, protected cultivation has eased the process of crop diversification and ensured enhanced income. Increasing demand for fresh vegetables in the urban areas is playing an important role in increasing adoption of protected cultivation.

Table 4.3: Government Schemes for Protected Cultivation in Haryana

	Subsidy (percent)	Remarks
High-Tech Greenhouse, NVPH, Poly Net House, Walk in Tunnel, Anti-Insect Net House	50	Max limit 4000sqm; higher subsidy (65 percent Gen, 85 percent SC) for Haryana
Bhavantar Bharpayee Yojana		Incentivize farmers to offset the losses during low prices in the market for perishable horticultural commodities. 21 horticulture crops included
Plant Subsidy	-	Rs. 4.25 paisa/plant
Replacement of Cladding Material	70	Cost of plastic sheet, Insect Net, Shade Net material like clumps
Plastic Tunnel	50	Max limit 10,000 sqm
Plastic Mulching	50	Max limit 20,000 sqm
Aeroponics	35	Up to 1000 sqm
Hydroponics	35	Up to 4000 sqm

Source: Horticulture Division, Government of Haryana

THE CASE OF PUNJAB

There has been increasing adoption of polyhouse technology for vegetable cultivation in several districts of Punjab. The major crops cultivated under protected environment includes cucumber, capsicum, squash, and tomato, which are highly appropriate for controlled environment.

Field level studies show that like Haryana, farmers in Punjab also experienced noteworthy improvement in both yield and profitability under protected cultivation. For instance, cucumber yield in polyhouse was 347 quintals per acre compared to 166 quintals per acre in open field. The analysis of finances also confirmed high economic viability of protected cultivation even with higher initial capital cost (Rani et al, 2024).

The promotion of polyhouse technology in Punjab has been reinforced by government subsidies and extension services. However, farmers still meet with challenges such as high initial capital costs, lack of technical knowhow, and insufficient awareness about advanced cultivation practices.

HIMALAYAN STATES

Protected cultivation became popular in the Himalayan states of Himachal Pradesh, Jammu and Kashmir, and Sikkim due to climate related challenges and lesser scope to expand open field cultivation for major parts of the year. In these states polyhouses offer an opportunity to cultivate vegetables in colder months when open field cultivation is impossible.

Studies undertaken under MIDH programme reveals that protected cultivation enabled smaller farmers in these regions to derive higher income from the cultivation of high-value crops. The technology also allows production of crops in regions where climatic conditions are highly variable.

However, constraints in these states include delay in subsidy payments, hindrances in accessing loans, high transportation costs, and limited marketing infrastructure. Farmers also faced challenges in marketing their produce indicating the need for better market linkages and cold chain infrastructure (Meenakshi & Chattopadhyay, 2018).

TELANGANA

The establishment of greenhouses/polyhouses has been implemented as a flagship programme in Telangana since 2014–15, with the objective of promoting the cultivation of high-value vegetables and flowers through substantial capital support. The scheme provides a subsidy of 75 percent to farmers, which was further enhanced to 95 percent for Scheduled Caste (SC) and Scheduled Tribe (ST) farmers from 2016–17 onwards, thereby improving inclusivity and accessibility. Under the programme, beneficiaries in the general category are eligible for assistance ranging from a minimum of 200 square metres to a maximum of 12,000 square metres (3 acres), while SC/ST farmers are eligible for support up to 1 acre. The scheme is designed to enhance productivity and yield per unit area, facilitate the adoption of high-value horticultural crops under protected cultivation, and enable year-round production, particularly focusing on off-season vegetable cultivation. Since its inception, the programme has covered approximately 1,150 acres across the state, benefiting 917 farmers. Of this, cultivation activities have been initiated on nearly 700 acres, while the remaining area is at various stages of implementation, reflecting both the progress and ongoing expansion of the initiative (Telangana Horticulture Department).

EXPERIENCE IN OTHER STATES

Apart from the states discussed above, protected cultivation has also been adopted in other states as well in different capacity. This includes states like Maharashtra, Tamil Nadu, Gujarat, and Uttarakhand. They have implemented different forms of protected structures depending on climatic condition, cropping pattern, and the capacity to take risk (**Table 4.4**).

Despite the development of protected cultivation in these states, adoption remains insufficient in many regions due to restrictions such as high initial investment costs, lack of technical knowhow, fragmented landholdings, and scarce extension support. Yet, the technology continues to gain importance as a means of improving productivity and resilience in the horticulture sector.

Table 4.4: Protected Cultivation in Major States

State	Protected Crops	Type of Structures Used	Key Drivers	Major Challenges
Karnataka	Capsicum, Cucumber, Tomato, Flowers	Polyhouses, Shade-net houses	Strong horticulture base, access to Bengaluru market, subsidy support	High investment cost, need for skilled management
Haryana	Tomato, Capsicum, Cucumber, Leafy Vegetables, Flowers	Naturally ventilated polyhouses, net houses	Proximity to NCR markets, Indo-Israel centres of excellence, government subsidy	High operational cost, limited technical knowledge
Punjab	Cucumber, Capsicum, Tomato	Polyhouses and Plastic Tunnels	High productivity potential, extension support	High capital requirement, technology gaps
Himachal Pradesh	Tomato, Capsicum, Flowers	Low-cost polyhouses	Climate suitability, government schemes	Marketing constraints, transport cost
Jammu & Kashmir	Vegetables, Flowers	Polyhouses	Cold climate adaptation, subsidy support	Delays in subsidy disbursement, limited extension services
Sikkim	Vegetables, Flowers	Polyhouses and low-cost structures	Government support and training	Input availability and market access
Maharashtra	Vegetables, Flowers	Greenhouses / Polyhouses	Export-oriented horticulture	High cost of technology
Gujarat	Vegetables, Flowers	Greenhouses and net houses	Commercial horticulture and market linkages	Capital investment requirements

Source: Collected from literature

The experience of different states tells us that protected cultivation has a strong potential to revolutionize horticulture sector in India. In Karnataka, Haryana, and Punjab supports are provided through subsidies, research support, and market linkages, while Himalayan states have employed the technology as a climate-adaptation strategy for producing vegetables and flowers in unfavourable environment. However, challenges still remain in terms of high initial capital, technical intricacies, and marketing challenges. These issues need to be addressed through better extension services, access to credit, region specific technologies, for escalating protected cultivation and ensuring sustainability of horticulture production in India.

5 CAPSICUM AS A MODEL CROP

CAPSICUM AS A MODEL CROP

The previous discussion underscores the rising importance of protected cultivation as an approach for agricultural diversification and income enhancement in many Indian states. Among the many crops cultivated in protected environment, capsicum has appeared as one of the most widely adopted and economically feasible crops owing to its high market demand, appropriateness for controlled environments, and prospect for generating higher returns per unit area. In order to demonstrate the hands-on implications and economic potential of protected cultivation, it is imperative to first recognize the crop profile of capsicum, its agronomic characteristics, and the trends in its production in India, value chain and profitability as these features provide the necessary background for measuring the performance and prospects of capsicum cultivation under protected conditions.

5.1 AREA, PRODUCTION, AND YIELD OF CAPSICUM IN INDIA

Capsicum is one of India's fastest-growing high-value vegetables, cultivated both under open and protected conditions. It gained popularity among farmers because of its unique position among vegetable crops due to its market worth, and nutritional value. In recent years capsicum has transitioned from a niche hilly crop to one of the major winter vegetable crops in plains and peri-urban zones. Change in dietary preferences played an important role in the growth of capsicum production in India.

TRENDS IN AREA, PRODUCTION, AND YIELD

Data from 2011-12 to 2024-25 reveals steady growth in the production of the crop (**Table 5.1**). Area under capsicum increased from 10 thousand ha in 2011-12 to 41 thousand ha in 2024-25. Over the same period, production improved from 127 thousand tonnes to 659 thousand tonnes, while productivity increased from 13.2 tonne/ha to 16 tonne/ha.

Table 5.1: Trends in Area, Production, and Yield of Capsicum

	Area ('000 ha)	Production ('000 tonnes)	Yield (tonne/ha)
2011-12	10.0	127.0	13.2
2012-13	29.1	153.4	5.3
2013-14	29.7	166.9	5.6
2014-15	32.1	182.5	5.7
2015-16	46.0	288.5	6.3
2016-17	23.8	306.1	12.8
2017-18	24.3	325.7	13.4
2018-19	33.7	496.7	14.7
2019-20	33.8	534.5	15.8
2020-21	37.2	563.0	15.2
2021-22	37.2	585.6	15.7
2022-23	40.0	642.9	16.1
2023-24	41.0	647.1	15.8
2024-25	41.1	659.2	16.0

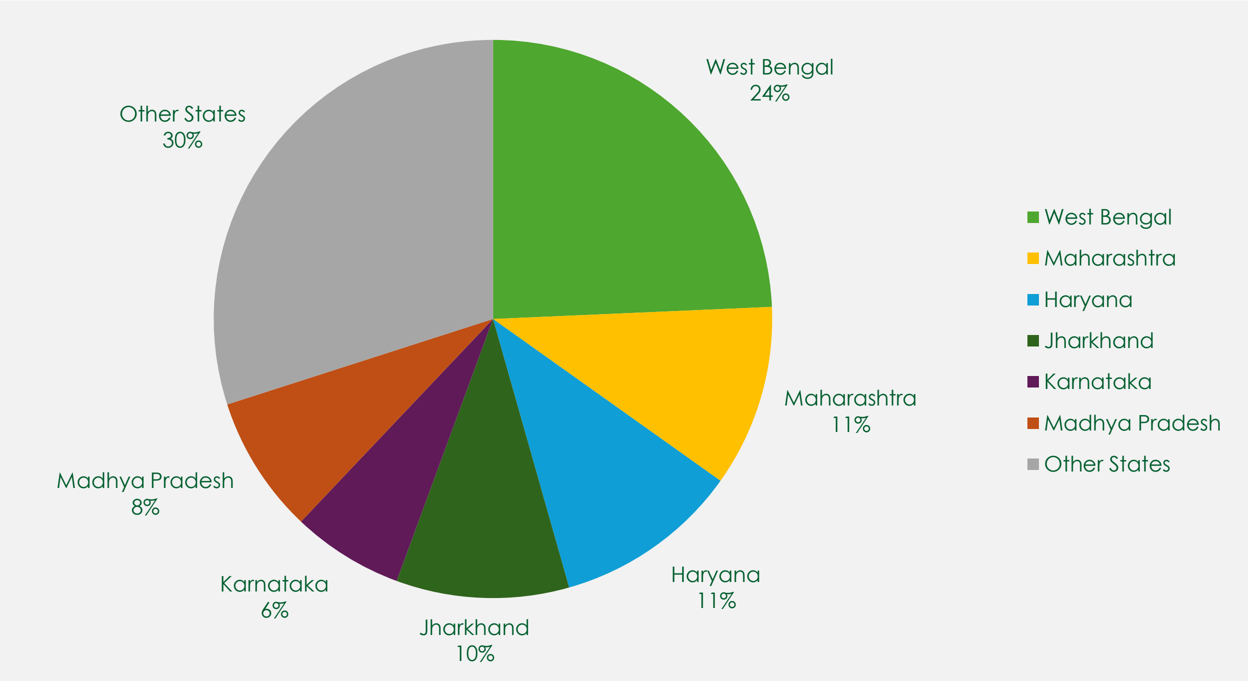
Source: Horticulture Statistics, Ministry of Agriculture

There have been variations in production in the initial years mainly due to climatic variability the stable yield gains after 2016 reflect technological progress, improved hybrid seeds, and expansion of polyhouse production systems.

5.2 REGIONAL PATTERNS

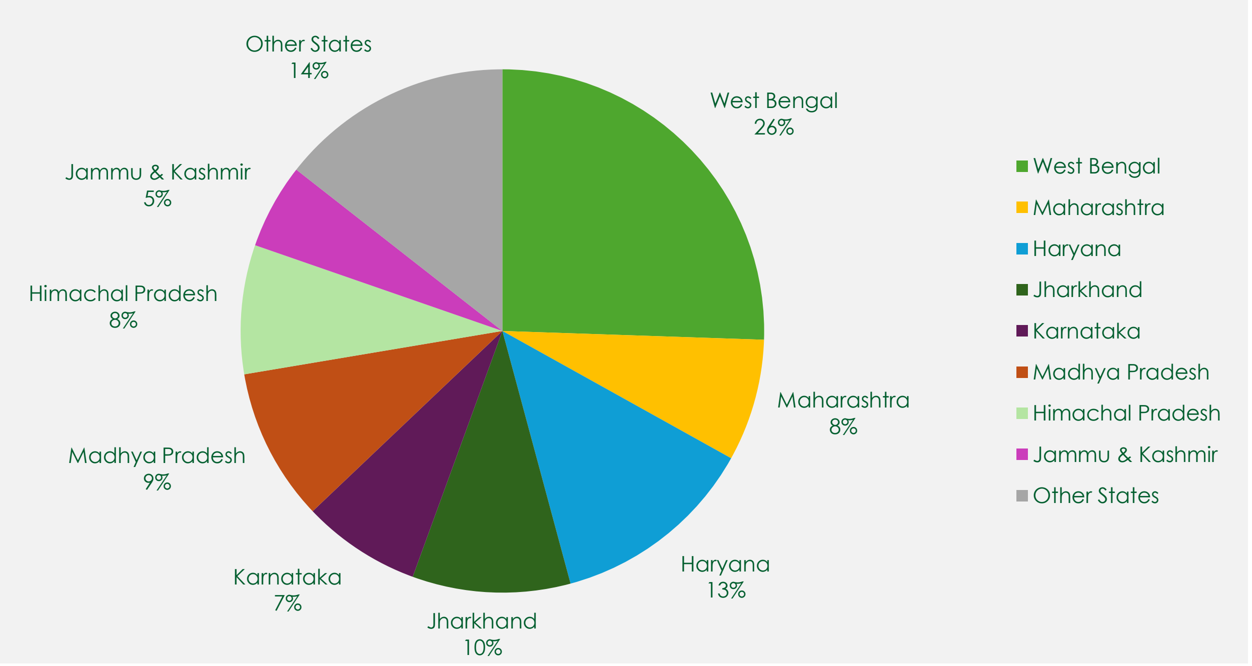
State-wise analysis shows that West Bengal, Maharashtra, Haryana, and Jharkhand contribute majorly in national output (**Figure 5.1** & **Figure 5.2**). Karnataka dominates in protected cultivation, supported by state subsidies and proximity to urban markets like Bengaluru. Himachal Pradesh and Uttarakhand rule hill production, while Haryana and Punjab have emerged as important peri-urban centres due to strong infrastructure and marketing linkages with NCR.

Figure 5.1: State-wise Area under Capsicum Crop, TE 2024-25



Source: Horticulture Statistics, Ministry of Agriculture

Figure 5.2: State-wise Production of Capsicum, TE 2024-25



Source: Horticulture Statistics, Ministry of Agriculture

The increase in capsicum production is principally attributed to policy support through the MIDH, NHM, and state subsidy schemes promoting protected cultivation. The AERC Shimla (2017) report documented over 415 ha area brought under polyhouses in Sikkim and rapid expansion in Himachal Pradesh and J&K, where capsicum was one of the principal vegetables grown under protected conditions. Similarly, Haryana's Working Group Report (2011) recognized polyhouse capsicum as a main driver of peri-urban diversification and off-season vegetable supply.

5.3 PRODUCTIVITY PERFORMANCE AND SOURCE OF GROWTH

Yield gains are the outcome of a combination of factors like acceptance of protected cultivation, hybrid varieties (such as 'Indra', 'Bomby', and 'Delisha'), precision nutrient management, and use of growth regulators. Similarly, studies in Rajasthan (Jain et al 2021) reported 2–3 times better productivity under polyhouses than in open cultivation, with significantly lower pest and water losses. In the Himalayan states, net returns from capsicum in polyhouses averaged Rs. 1.5 lakhs per structure, with minimal post-harvest losses (≈2 percent) (Meenakshi & Chattopadhyay, 2018).

Reasons for Growth

Technological Innovations – Wider dissemination of polyhouse and shade-net technologies, fertigation, drip irrigation, and the use of growth hormones such as planofix (NAA) have improved fruit set and marketable yields by 30–40 percent.

Policy and Institutional Support – Government subsidies under MIDH, NHM, and RKVY have made protected structures economically viable. States like Karnataka, Haryana, Uttar Pradesh, and Himachal Pradesh provide up to 50–70 percent subsidy for polyhouse installation.

Market Expansion and Value Addition – Rising urban demand for coloured bell peppers and fast-food industry linkages have enhanced profitability, inspiring area substitution from low-value cereals and pulses

Climate Resilience and Off-Season Advantage – Protected cultivation shields climatic challenges, predominantly in hill and semi-arid states where temperature fluctuations disturb open-field yield. Studies highlight high input-use efficiency, year-round cropping, and reduced pest incidence under polyhouses.

Area-led vs. Yield-led Growth

The change in production was decomposed into area effect, yield effect, and interaction effect following the Minhas decomposition method. It reveals that area effect contributed about 91.4 percent to the total increase in production, while yield effect contributed about 49.3 percent. The interaction effect was negative, contributing about -40.7 percent to production growth (**Table 5.2**). The negative interaction effect indicates that increase in cultivated area may have taken place on comparatively less productive land, which reduced the joint impact of area and yield on production growth. Since the contribution of area effect was higher than yield effect, the results indicate that production growth during the study period (2011-12 to 2025-26) was largely area-led rather than yield-led. This tells us that production growth was extensive in nature, determined mainly by expansion in cultivated area rather than enhancements in productivity. However, expansion in cultivated area is subject to natural resource constraints and cannot withstand production growth in the long run. Therefore, future growth in production must gradually come from progresses in productivity rather than area expansion. In this context, protected cultivation can play a noteworthy role by improving yield per unit area, and input use efficiency, reducing weather-related risks, and enabling cultivation of high-value crops. By shifting the growth process from area-led to yield-led growth, protected cultivation can contribute to sustainable production growth and higher farm income without necessitating expansion in cultivated land.

Table 5.2: Decomposition of Production Growth into Area, Yield, and Interaction Effects (Minhas Decomposition Method), 2011-12 to 2024-25

Effect	Contribution
Area	91.47 percent
Yield	49.27 percent
Interaction	-40.74 percent

Source: Estimated by authors

5.4 VALUE CHAIN ANALYSIS OF CAPSICUM

The capsicum value chain consists of various stakeholders beginning with input supply and ending with final consumption. The major stakeholders include input suppliers, farmers, aggregators or commission agents, wholesalers, retailers, and consumers. As a high-value vegetable crop, capsicum plays a vital role in the horticulture sector due to its niche market demand in the urban areas, catering and hospitality sector, high nutritional value, and suitability for protected cultivation systems. Each stage of the chain executes precise functions such as production, aggregation, transportation, storage, and retail distribution, adding to the complete value addition of the product. The efficacy of the value chain hinge on the synchronization among these stakeholders and the functioning of marketing channels.

Input Supply and Production

The discussion on the value chain of capsicum begins with the availability and access to essential inputs for cultivation. These include high yielding varieties of seeds, fertilizer, pesticides and chemicals, irrigation equipment, bamboo and plastic material for greenhouse and so on. Additionally, capsicum like any other horticulture crops require human labour for activities like land preparation, planting, irrigation, mulching before planting the crops and manuring, pruning, plant protection, stalking and support in the post planting phase. Under protected cultivation system, there are some additional activities like managing environmental conditions, such as temperature and humidity to optimize fruit growth and quality. A focussed group discussion with farmers revealed that access high quality seeds continue to be a challenge for the farmers in horticulture generally and capsicum in particular. Although states like Haryana, and Uttar Pradesh have schemes for distribution of high-quality seeds through various programmes, many farmers reported difficulties in accessing these schemes due to limited availability, bureaucratic hassles, and lack of awareness. These challenges are more severe for the small and marginal farmers. As a result, farmers are often forced to rely on buying seeds from private supplies at relatively elevated prices.

The A2[4] cost of cultivation for capsicum varies significantly between open-field and polyhouse systems, reflecting differences in input intensity, technology adoption, and production practices. In open-field cultivation, the total cost is estimated at

[4] A2 cost of cultivation covers all actual paid-out costs directly incurred by farmers in cash or kind, including expenses for seeds, fertilizers, pesticides, hired labour, fuel, and irrigation.

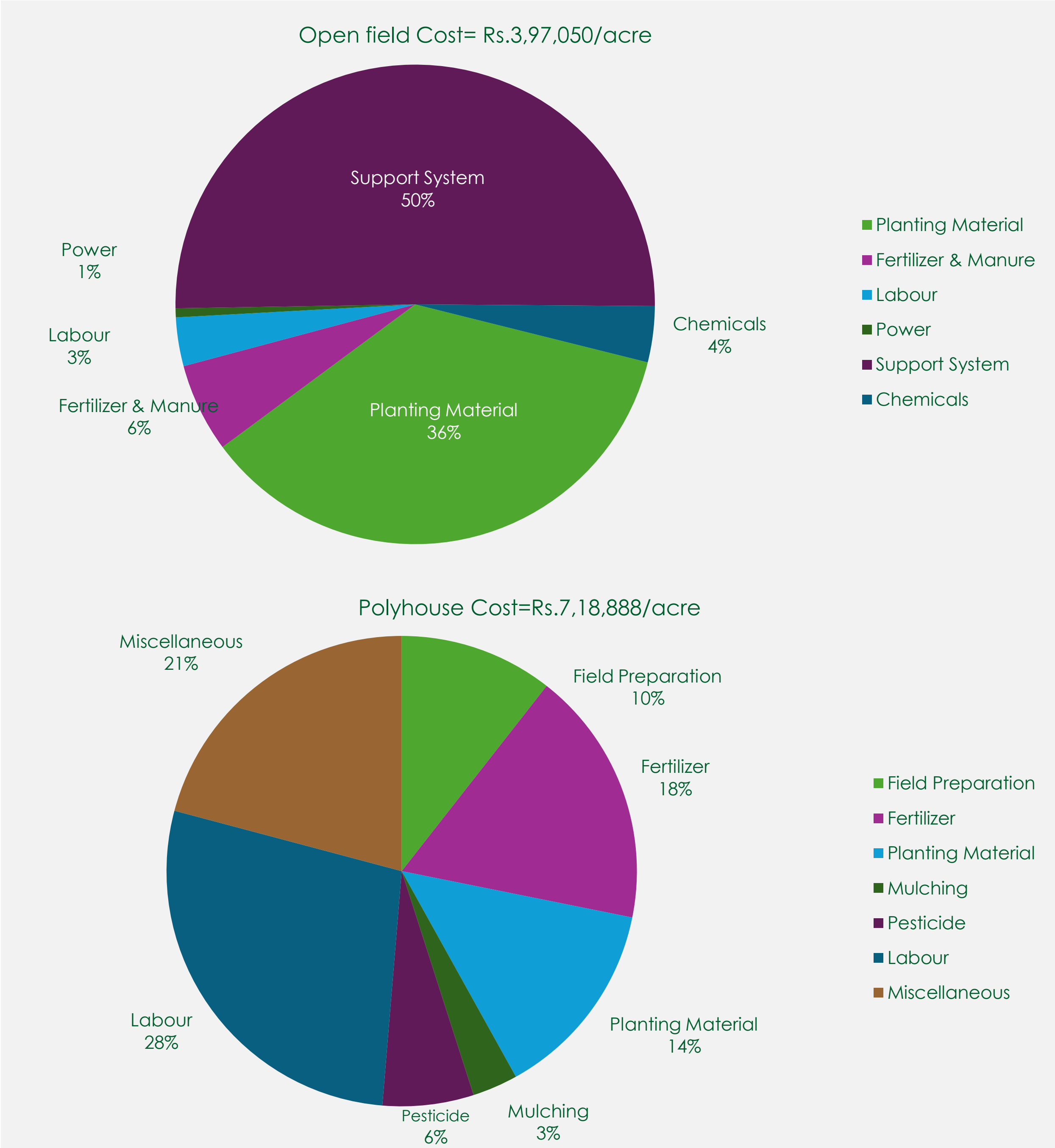
around Rs. 3.97 lakhs per acre, with planting material (36 percent) constituting the largest share, followed by field preparation (10.6 percent) and relatively modest expenditures on fertilizers (6 percent), labour (3.3 percent), and chemicals (3.8 percent). The cost structure indicates a low-input system with limited use of advanced inputs and infrastructure (**Figure 5.3**).

In contrast, polyhouse cultivation involves a substantially higher total cost of approximately Rs. 7.19 lakhs per acre[5], nearly 1.8 times that of open-field farming. The cost structure is also more diversified and input-intensive. Major cost components include labour (27.8 percent), fertilizers (17.6 percent), and planting material (13.8 percent), along with additional expenses on mulching (3.1 percent), pesticides (6.3 percent), and significant miscellaneous costs (20.9 percent), which typically include maintenance and operational expenses of the protected structure (**Figure 5.3**).

A key distinguishing factor is the presence of capital-intensive elements in polyhouse cultivation, such as support systems and controlled input application, which are either absent or minimal in open-field systems. While open-field cultivation is less risky in terms of upfront investment, it is more vulnerable to climatic variability and yield fluctuations. Conversely, polyhouse cultivation entails higher initial and operational costs but offers better control over growing conditions, leading to improved productivity, quality, and potential price realization.

[5] The cost of cultivation data is obtained from various case studies presented by Agriplast website. This cost structure varies marginally from the cost collected at field for this study.

Figure 5.3: Cost Component of Capsicum in Open field versus Polyhouse



Source: National Horticulture Board, Agriplast, Field information

Marketing Channels in the Capsicum Supply Chain

The marketing of capsicum typically follows various channels involving different stakeholders through which farmers sell their produce. The commonly observed channels include:

- Producer → Consumer (Direct marketing)
- Producer → Retailer → Consumer
- Producer → Commission Agent → Retailer → Consumer
- Producer → Local Trader → Wholesaler → Retailer → Consumer
- Producer → Wholesaler → Retailer → Consumer

The marketing channel consisting of producer, commission agent, retailer, and consumers is the most common form of supply chain in capsicum. The largest share of output is marketed through this channel in India. This shows importance of commission agents in linking producers and consumers in the supply chain of capsicum. A study by Thakur et al (2024) highlights that around 47 percent of output is traded through this channel, followed by 21.5 percent output channelled through producers, local traders, wholesalers, retailers, and consumers. Moreover, the Producer–Retailer–Consumer channel is adopted for 8.50 percent of trade, the producer sells the capsicum to a retailer, who in turn sells it to the end consumer. Direct marketing channels such as producer-to-consumer sales are more effective because they reduce intermediary costs and increase the producer's share in the consumer rupee. However, these channels are used by very few farmers due to logistical constraints, restricted market access, and lack of knowledge.

Price Spread and Value Distribution

A vital aspect of value chain analysis is the distribution of value generated among different stakeholders. In vegetable crops, the price paid by consumers is usually much higher than the price received by farmers due to seasonal nature and perishability of the crops.

The price spread between the farm-gate price and the retail price reproduces the cumulative costs associated with transportation, packaging, storage, and intermediary margins. Studies of capsicum marketing channels show that the producer's share in the consumer price varies significantly across different marketing channels.

Channels involving less intermediaries tend to offer a higher share of the consumer price to producers. For instance, direct marketing with retail platform allows farmers to capture a considerably greater portion of the final price. However, these channels are often controlled by limited market access and logistical challenges. In contrast, longer marketing channels involving multiple intermediaries increase marketing costs and reduce the share of farmers in the final consumer price.

Table 5.3: Price Spread and Farmer Realization in Open Field versus Polyhouse Cultivation (Rs/kg), TE 2024-25

	Wholesale Price	Retail Price
Green Capsicum (open field)	Rs. 22-30 (open market) Rs. 45-50 (Online platform)	Rs. 55-60 (open market) Rs. 85-90 (online platform)
Coloured Capsicum (Polyhouse)		
(A+ grade)	Rs. 120	Rs. 500
A grade	Rs. 100	Rs. 450
B grade	Rs. 80	Rs. 450
C (Processing Variety)	Rs. 50	
English Cucumber (Polyhouse)		
	Rs. 15-25 (Local mandi)	Rs. 30-40 (Retail Market)
	Rs. 20-30 (Wholesale Mandi)	Rs. 60-70 (Online Platform)
	Rs. 25-35 (Contract farming with hotels/restaurants)	

Source: Market Intelligence, AGMARKNET, Agriplast, Blinkit, Zepto

For green capsicum (open field), farmers obtain about Rs. 22–30/kg in traditional mandis, while those linked to organized or online platforms may realize relatively higher prices of Rs. 45–50/kg. However, these are still noticeably lower than retail prices, which range from Rs. 55–60/kg in open markets to Rs. 85–90/kg on online platforms, indicating a large gap between farm-gate and consumer prices.

For coloured capsicum (polyhouse), farmer realizations are higher due to premium quality and controlled cultivation, but the price spread remains pronounced. Farmers receive around Rs. 120/kg for A+ grade, Rs. 100/kg for A grade, Rs. 80/kg for B grade, and Rs. 50/kg for processing-grade produce, whereas retail prices for premium grades reach Rs. 450–500/kg. This indicates that despite higher-value production, a significant share of the consumer price is captured beyond the farm level (**Table 5.3**).

The table also highlights English cucumber (polyhouse), where farmer realization varies by market channel. Prices range from Rs. 15 - 25/kg in local mandis, Rs. 20 - 30/kg in wholesale markets, and can go up to Rs. 25 - 35/kg under contract farming arrangements with hotels and restaurants. In contrast, retail prices range from Rs. 30 - 40/kg in traditional markets to Rs. 60 - 70/kg on online platforms, again pointing to higher margins in downstream segments.

The emergence of online grocery platforms such as Blinkit, Zepto and Swiggy Instamart has shaped new marketing avenues for farmers producing horticulture crops, mostly for high-value vegetables like capsicum. These platforms generally procure vegetable items from the farmers through organized supply chains but follow stringent quality standards. The procurement process goes through strict grading for uniformity of colour, size, shape, and freshness. Farmers those are capable of meeting those standards sell a substantial share of their produce to these platforms guaranteeing better price realization and stable demand. These platforms minimize the number of intermediaries in the supply chain, which can increase the farmers' share in consumer rupee. However, since procurement by online retail platforms is generally limited to premium grade produce, farmers need to rely on traditional APMC channels for selling inferior quality output. Moreover, online platforms cater to a niche urban market hence can procure only a small share of total country's produce. As a result, significant share of the produce continues to be channelled through APMC mandis. Therefore, despite the increasing presence of digital retail platforms, APMC markets remain the primary outlet for most farmers, providing an important mechanism for absorbing large volumes of produce and enabling farmers to sell both premium and lower-grade outputs.

Implications for Protected Cultivation

The adoption of protected cultivation technologies such as polyhouses and shade-net houses has the potential to significantly enhance the capsicum value chain. Protected cultivation enables farmers to produce high-quality capsicum with higher productivity and better consistency in supply. Moreover, coloured (red, yellow, orange) capsicum can only be produced in a protected environment. The coloured capsicum is sold at the retail market at much higher prices in the range of Rs. 450-500/kg. In a controlled environment harvesting starts during November and goes on till the month of March, with farmers receiving higher price as market supply reduces.

However, the benefits of protected cultivation can only be fully grasped if efficient marketing systems can be ensured. Strengthening value chains through improved infrastructure, better market information systems, and farmer aggregation mechanisms such as FPOs can help farmers achieve better price realization and improve the overall efficiency of the capsicum supply chain.

Processing of Capsicum

Capsicum processing in India is still at a nascent stage, but has a lot of potential driven by growing demand for value-added products such as pickles, dehydrated capsicum, and ingredients for the food service industry. Given the highly perishable nature of capsicum and its high moisture content, processing offers a critical avenue to reduce post-harvest losses and stabilize farmers' income. Farmers sell lower-grade produce to processing units at around Rs. 50/kg, enabling them to recover some value that would otherwise be lost if the produce were discarded. The sector shows strong commercial potential, particularly for niche products like chilli pickles and dehydrated variants, which have both domestic and export demand. However, the industry is characterized by relatively high initial capital requirements and working capital needs estimated at around Rs. 20–21 lakhs for a small-scale unit, with significant allocation toward machinery and working capital. Despite this, financial indicators such as a break-even point of around 23 percent and a payback period of approximately 5 years suggest economic viability (MSME project Report). Going forward, scaling capsicum processing will depend on improving access to affordable credit, strengthening backward linkages with farmers, and developing market channels for processed products.

Challenges of Capsicum Value Chain

The capsicum value chain in India faces various structural and operational limitations that limit its efficiency and diminish the share of value accruing to farmers. One of the major challenges faced by farmers is the lack of access to consistent market information and extension services, which restricts farmers' ability to make informed decisions about the timing of sales, market selection, and price negotiation. Moreover, inadequate transport facilities, particularly the absence of reefer trucks sets back timely movement of harvest from farms to markets. Given the highly perishable nature of capsicum, disruptions in transportation often result in post-harvest losses and deteriorating product quality. Another noteworthy restriction arises from the high commission charges and marketing fees imposed by intermediaries, which inflate the overall marketing cost and reduce the producer's margin. Farmers are often compelled to rely on commission agents and traders to access wholesale markets, thereby limiting their bargaining power within the supply chain.

Moreover, price volatility and unsatisfactory farm-gate prices characterize persistent challenges for capsicum growers. Disparities in supply, seasonality, and inadequate storage facilities contribute to uneven price realization for farmers. The absence of adequate cold storage, grading, and packaging infrastructure further worsens these problems, compelling farmers to sell their produce right after harvest, often at unfavourable prices. Additionally, farmers face logistical difficulties which disrupt market linkages and result in marketing inefficiencies. These constraints jointly deteriorate the functioning of the value chain and underscore the need for targeted policy interventions intended at strengthening infrastructure, improving market information systems, reducing intermediary costs, and promoting farmer collectives such as FPOs to enhance farmers' bargaining power and overall value chain efficiency.

6 COLOURED CAPSICUM IN PROTECTED CULTIVATION

COLOURED CAPSICUM IN PROTECTED CULTIVATION

This section analyses three case studies of coloured capsicum (bell pepper) cultivated under protected structure and controlled environment in the northern parts of India. The objective is to comprehend the technical, economic, and managerial aspects of protected cultivation in India. This helps in understanding the differences in productivity and profitability across systems covering low cost naturally ventilated shade-net and more capital-intensive polyhouse systems.

Haryana and Uttar Pradesh have been identified as the primary study locations because they represent regions where agriculture has historically been dominated by the traditional rice–wheat cropping system. This production structure is shaped by the Green Revolution strategy supported by government procurement policies and input subsidies. While this system has successfully guaranteed food security for the growing population in the post-independence era, it has also led to various structural challenges, including stagnant profitability, groundwater depletion, and soil degradation. In this context, crop diversification toward high-value horticulture has become a policy priority in both states. The shift from cereal-dominated systems to horticultural crops such as vegetables has potential to augment farm income, enable resource-use efficiency, and create stronger linkages with urban markets. Learning about protected cultivation within these states therefore provides an important angle to inspect how technological interventions can reinforce diversification and income augmentation in regions conventionally characterized by monoculture cereal production.

Haryana and Uttar Pradesh offer opposing yet balancing institutional and market environments that make them particularly suitable for comparative analysis. Haryana benefits from strong market access due to its proximity to the NCR, well-developed road infrastructure, which allow farmers to directly supply high-value vegetables to urban wholesale markets and institutional buyers. Uttar Pradesh, particularly the peri-urban regions around Lucknow, signifies an emerging horticultural cluster where younger agripreneurs are experimenting with protected cultivation integrating with modern supply chains, including digital retail platforms and organized retailers. These differing contexts permit the study to capture how disparities in market access, subsidy volume, technological adoption, and entrepreneurial dynamics impact the profitability and scalability of protected cultivation systems. Such an evaluation provides deeper insights into the role of regional characteristics in shaping the transition toward high-value horticulture in northern India.

The study collects field level data on area, fixed installation cost (with subsidy), yield, price realization, variable costs and net returns for three case studies. Quantitative estimates along with qualitative assessment of subsidy incidence, crop management intensity, and market access have been presented in the following section.

6.1 ECONOMICS OF PROTECTED CULTIVATION

Field level information confirms that protected cultivation has emerged as a technological intervention in horticulture crops such as coloured capsicum, cucumber, and exotic leafy vegetables like lettuce. By creating controlled microclimatic conditions, these systems enable farmers to improve plant growth, extend the production season longer than permitted by natural environment, and harvest superior-quality vegetables apt for premium markets. The economic practicability of such systems relies on several aspects including installation cost, productivity performance, market price realization, and operational expenditure.

The present analysis draws on three farm-level case studies: one from Karnal district in Haryana and two from Lucknow district in Uttar Pradesh. These cases offer understandings of the economic performance of naturally ventilated shade net houses and polyhouse systems under different institutional and market conditions.

Cost Structure and Investment Requirements

Protected cultivation necessitates substantial capital investment for building the structure. It requires items like structural frames, polyethylene cladding, drip irrigation systems, fertigation units, and so on. In the Haryana case, a naturally ventilated shade-net house installed on one acre required an investment of approximately Rs. 28 lakhs. Government subsidy under the MIDH covered about Rs. 18 lakhs, reducing the effective farmer investment to Rs. 10 lakhs.

In contrast, polyhouse systems require considerably higher capital costs owing to modern technologies installed in the structure. In the Lucknow district cases, installation costs ranged between Rs. 45.5 lakhs to Rs. 52 lakhs for a one-acre polyhouse. Even after subsidy provision, the farmer's capital burden remains large. This high upfront investment signifies one of the most critical barriers to adoption, particularly for smallholders.

In this context, the study finds that the range of subsidy support for protected cultivation differ significantly across states. In Haryana, government support covered a substantial share of the installation cost, amounting to nearly 65-70 percent in some cases. In contrast, in Uttar Pradesh the subsidy support is relatively lower, typically ranging between 35 and 45 percent of the total installation cost, depending on the scale of the project and the level of technological advancements adopted by the farmer.

6.2 YIELD AND PRODUCTIVITY PERFORMANCE

Productivity achieved in polyhouse system of cultivation is substantially higher compared to the yield achieved in traditional open-field cultivation. The polyhouse case in Uttar Pradesh (Lucknow) recorded yields of approximately 24-35 tonnes per acre for coloured capsicum, considerably higher than the 12 tonnes per acre achieved under naturally ventilated net house cultivation in Haryana (Karnal).

The difference in productivity reflects the advantages of polyhouses over net houses in keeping ideal temperature, moisture, and nutrient supply through fertigation. Moreover, better pest and disease control in the protected environments contributes to better crop health and higher marketable yield.

As coloured capsicum is fit to be produced in protected environment, its productivity cannot be compared with the green capsicum produced under open-field condition. However, the yield of green capsicum produced in the open field under natural condition stood at 6.47 tonnes/acre at all India level in 2025-26.

6.3 REVENUE AND PROFITABILITY

Protected cultivation offers higher revenue due to better yield, premium quality, and access to high-value market. In the Haryana case, despite lower yield, the farmer earned a relatively high market price of Rs. 100 per kilogram due to proximity to the NCR markets and strong demand from institutional buyers.

In contrast, the polyhouse cases in Uttar Pradesh recorded an average price of approximately Rs. 80 per kilogram, with variations between Rs. 60 and Rs. 110 depending on seasonal supply conditions. However, farmers managed to generate higher revenue as better yield compensated for the slightly lower price realization.

Gross revenue per acre for one season ranged from around Rs. 12 lakhs under net house cultivation to Rs. 28 lakhs under polyhouse cultivation. Just considering for variable costs such as seeds, fertilizers, labour, irrigation, and packaging, profit ranged from Rs. 8.9 lakhs per acre in the shade net (Haryana) case to nearly Rs. 19.5 lakhs per acre in the Polyhouse (Uttar Pradesh) case. However, if annualised fixed cost is incorporated with variable cost, net return ranged from 7.9 lakhs per acre in shade net cultivation to 16 lacs in polyhouse cultivation for one cycle of capsicum.

Assuming a leveraged capital structure where 85 percent of the initial investment is debt-financed over a three-year tenure, the resulting EMI obligations significantly impact short-term liquidity; consequently, the projected net residual return is moderated to an estimated range of Rs. 5–7.5 lakhs per acre during the amortization period.

6.4 COST OF CULTIVATION AND INPUT INTENSITY

The cost structure under protected cultivation is much more input-intensive than traditional farming systems. Variable costs include components like hybrid seeds, micronutrients, plant protection chemicals, labour for pruning and harvesting, and packaging for market transport.

The shade net case documented variable costs of about Rs. 3.08 lakhs per acre per production cycle. In contrast, the polyhouse systems in Uttar Pradesh required significantly higher expenditure around Rs. 6 lakhs to Rs. 8.5 lakhs per acre reflecting the higher input intensity and labour requirements of intensive horticulture systems.

However, the elevated cost under the protected system is balanced by better yield and improved quality, that resulted in higher return compared to traditional cropping systems.

Comparative Economic Performance

A comparison of the three cases highlights the strong economic potential of protected cultivation (**Table 6.1**).

Table 6.1: Comparative Economic Performance of Capsicum Cultivation under Protected Structures: Case Studies from Haryana and Uttar Pradesh

	Naturally Ventilated Net Cultivation (Case 1)	Polyhouse Cultivation (Case 2)	Polyhouse Cultivation (Case 3)
Location	Sangoha Village, Karnal Block, Karnal District, Haryana	Harikhera village, Mohanlalganj Block, Lucknow District, Uttar Pradesh	Gaura village, Mohanlalganj Block, Lucknow District, Uttar Pradesh
Farmer	Pawan Kumar	Anushka Jaiswal	Shubham Diwedi
Area under Capsicum Cultivation	3 acres	1 acre	0.5 acre
Total Area under Cultivation	**3 acres (Capsicum)**	**3 acres (English Cucumber, coloured Capsicum, Exotic vegetables)**	**2.5 acres (Cucumber, Coloured Capsicum)**
Fixed Cost of Installation	28 lakhs (Govt Subsidy 18 lakh) @1 acre	52 lakhs (Govt Subsidy 17 lakh) @ 1 acre	22.75 lakh (Govt Subsidy 10.3 lakh) @ 0.5 acre
Annualised Fixed Cost (AFC) (Rs/acre) (Assuming project life=10 years)	Rs. 1,00,000	Rs. 3,50,000	Rs. 2,49,000
Yield (tonne/acre)	12	35	24
Price (Rs/kg)	100	80 (Max 110, Min 60)	80-90
Revenue (Rs/acre)	12,00,000	28,00,000	20,40,000
Variable Cost (Rs/acre) (VC)	3,08,280	8,50,000	6,00,000
Net Return (Rs/acre) (based on VC)	8,91,720	19,50,000	14,40,000
Net Return (Rs/acre) (based on AFC+VC)	7,91,720	16,00,000	11,91,000
Net Return (Rs/acre) (first three years adjusting loan)	5,04,000	7,23,000	5,74,000

Source: Collected from field

6.5 RISK AND SENSITIVITY ANALYSIS

Even though protected cultivation guarantees high profitability potential, it is accompanied with significant risks arising from market fluctuations, production uncertainties, and capital exposure. A systematic evaluation of these risks is important to assess the long-term sustainability of the investment.

Market Risk

Price volatility is identified as one of the most important risks in horticultural production. Capsicum prices vary widely depending on seasonal supply conditions and competition from other producing regions.

Farmers in Haryana enjoy price advantage compared to other states owing to its geographic proximity to Delhi and NCR markets. The region's well-developed road networks and closeness to Azadpur mandi allow fresher produce to reach wholesale markets fast, minimizing post-harvest losses and safeguarding higher farm-gate prices. Farmers stated that retail and wholesale demand from Delhi restaurants, hotels, and institutional buyers helps get better prices for coloured capsicum in Haryana, as high as Rs. 100/kg, and during periods of seasonal scarcity they have touched Rs. 200–Rs. 250/kg. As a result, farmers in Haryana are less dependent on digital retail platforms such as Blinkit or Zepto, which are profitable in markets like Lucknow where local price realization is lesser and farmers rely on these platforms to fulfil urban demand. In Haryana, direct marketing to NCR mandis or bulk buyers often receives better margins with a smaller number of intermediaries, making platform-based procurement models comparatively less attractive. This benefit of closeness to NCR partly neutralises some production risks.

In Lucknow, Output is marketed through both traditional and modern channels: 80 percent sold to Dubagga mandi through local arhatiyas; 20 percent sold to Blinkit and Lulu Mall outlets, offering Rs. 20/kg premium for superior quality. Hydroponically produced lettuce fetches Rs. 35 per 100g packet from Blinkit (retail price Rs. 120), representing strong value addition potential. However, perishability and compliance with packaging and quality standards levy extra costs. Transportation expenses average Rs. 1/kg. For bell pepper, Blinkit mostly acquires the cream produce due to their high-quality standards. Higher price is offered during the months when open field crop is not available. Initially Blinkit used to offer better price due to non-availability of open field crop beyond the month of March. However, in the recent years, fresh produce comes from Himachal Pradesh. Hence, higher price is only accessible for the months of May-December. During winter months, when open field crop is obtainable, average wholesale price for the bell pepper drops.

In this regard, it is important to highlight the case of Telangana, where adoption of protected cultivation technologies have been adopted by the farmers as government covers almost 75 percent of the installation cost in the form of subsidy. However, from the successful case studies it is found that farmers have generated a net return of around Rs. 5 lakhs /acre from one cycle of capsicum. As the average price received by the farmers were only Rs. 20/kg, it resulted in much lower return compared to what has been experienced in Haryana or Uttar Pradesh.

Hence it implies that market diversification strategies such as supplying to organized retailers, restaurants, and online grocery platforms can help reduce this risk by ensuring stable demand and better price realization.

Production Risk

Protected cultivation reduces exposure to climatic variability such as rainfall and temperature extremes. However, there has been instances of new biological risks linked with pest occurrences, nutrient imbalances, and disease management.

Despite its potential to ensure better yields and uniform quality, protected cultivation in Haryana faces significant functioning challenges. While polyhouse and net-house systems let producers cultivate beyond the growing season, farmers face a sharp decay in capsicum harvest after mid-December due to low light intensity and temperature drop, even under protected structures. This limits market advantage during the peak winter demand period.

High-density planting and intensive fertigation systems need careful monitoring to avoid pest attack. Failure to maintain optimal conditions can lead to rapid crop losses.

Capital Risk

The high capital cost of polyhouse infrastructure upsurges risk, particularly when farmers rely on credit to finance installation. Loan repayment obligations create pressure on cash flow during the initial years of operation.

Although polyhouses are more effective in preserving controlled micro-climatic conditions associated to naturally ventilated net-houses, their maintenance is considerably higher. Haryana experiences frequent storms, high winds, and dust events, which cause repeated damages of polyhouse. Field estimates show that annual renovation and replacement costs can reach up to Rs. 2 lakhs/acre, which significantly inflates the operational cost and erodes net returns. These risks make profitability uncertain, mainly for small and medium farmers who rely heavily on credit and subsidy support to adopt protected cultivation.

When the farmer financed part of the investment through bank loans, annual loan repayments estimate approximately in the range of Rs. 5 – 12 lakhs for three years. While the enterprise generated adequate revenue to service the loan, any reduction in yields or prices could significantly affect repayment capacity.

Sensitivity Analysis

To assess financial resilience, sensitivity analysis was undertaken under different scenarios of variation in price or yield. The results show that even under adverse conditions, protected cultivation proved to remain financially viable.

Under the base scenario (**Table 6.2**), the project generated an estimated NPV of approximately Rs. 84 lakhs and an internal rate of return (IRR) of 54 percent over a ten-year project life. In the pessimistic scenario (–20 percent price or yield), NPV declined to Rs. 50 lakhs and IRR to approximately 38 percent. However, in the absence of capital subsidies, the IRR undergoes a steep decline to 35 percent, this further goes down to 23.5 percent in adverse conditions of falling yield or prices. While the venture remains fundamentally viable as it exceeds the standard hurdle rate, this diminished return profile exhibits significant sensitivity to market and production volatility; specifically, any exogenous shocks such as a contraction in realized market prices or a deficit in agricultural yield could further erode the project's margin of safety.

Table 6.2: Sensitivity Analysis of Polyhouse Project

Scenario	Annual Net Income (in lakhs Rs) per acre	NPV (in lakhs Rs)	IRR (in percent)
Base Case	16	84	54
20 percent decline in Price/Yield	10.4	50.4	38.1
Without Subsidy	15.2	67	35.5
-20 percent Price/Yield (without Subsidy)	9.57	33.4	23.5

Source: Estimated by Authors

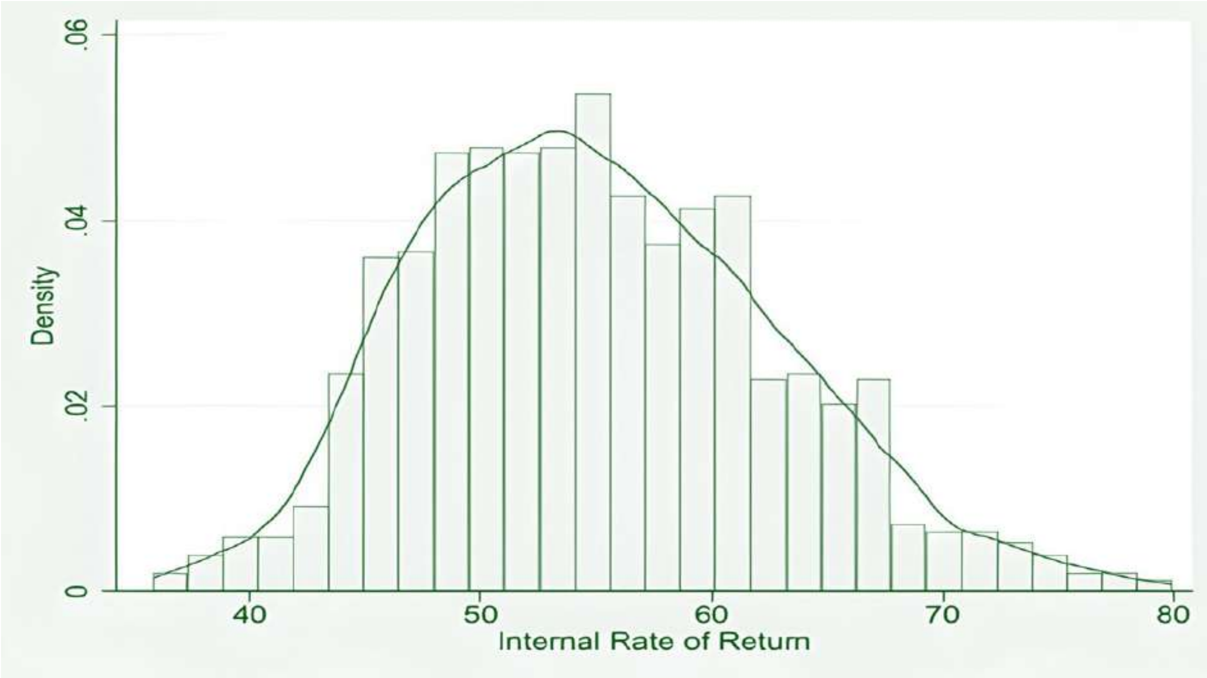
A Monte Carlo simulation was conducted to assess the variability and risk related with the IRR of the polyhouse capsicum cultivation project. The simulation was based on 1,000 iterations, where key variables affecting project profitability such as price, yield, and production costs were allowed to vary according to their assumed probability distributions. For each iteration, the project cash flows were calculated and the corresponding IRR was estimated. This approach enables the assessment of the range and likelihood of possible returns rather than relying on a single deterministic estimate.

The histogram presented above illustrates the distribution of simulated IRR values obtained from the 1,000 iterations. The horizontal axis represents the internal rate of return, while the vertical axis shows the probability density of the simulated outcomes. The distribution seems approximately normal, with most IRR values concentrated between 45 percent and 65 percent. The peak of the distribution occurs around 50–55 percent, signifying that this range represents the most likely return under the assumed production and market conditions.

The simulation results advocate that the polyhouse capsicum cultivation project generates consistently high returns across a wide range of scenarios. Even under relatively adverse conditions, the IRR remains considerably above the assumed discount rate of 10 percent, demonstrating strong financial viability. The right tail of the distribution shows that in favourable scenarios such as higher market prices or yields the IRR may exceed 70 percent, while the left tail indicates that returns could decline to around 35–40 percent in less favourable conditions.

Overall, the Monte Carlo analysis validates that the investment is robust to uncertainty in key parameters, with a high probability of making returns well above the cost of capital. This probabilistic assessment reinforces the financial evaluation of protected cultivation by incorporating risk and variability in production and market conditions, thereby providing a more complete understanding of the project's potential performance.

Figure 6.1: Monte Carlo Simulation of Internal rate of Return (IRR) for Polyhouse Capsicum Cultivation



Source: Estimated by Authors

6.6 FINANCE

Financial viability is a critical factor of adoption in protected cultivation systems. The capital-intensive nature of polyhouse infrastructure necessitates careful financial planning, including subsidy utilization, credit access, and cash flow management.

Role of Government Subsidies

Government subsidy programs under the MIDH significantly reduce the financial burden on farmers accepting protected cultivation technologies. Subsidies generally cover 40–50 percent of the estimated project cost, though actual construction outlays often surpass official cost norms.

In the Lucknow case of polyhouse construction, the official subsidy calculation was calculated based on a benchmark cost of Rs. 39.36 lakhs, while the actual installation cost reached Rs. 52 lakhs. As a result, the effective subsidy covered only about one-third of the total expenditure. Despite these limitations, subsidies play a crucial role in encouraging adoption by reducing the initial capital requirement.

Credit and Loan Financing

Farmers frequently rely on a combination of government loans, private loans, and personal savings to finance protected cultivation projects. In the Haryana case, the farmer obtained a Rs. 3 lakhs government loan at 7 percent interest and a Rs. 10 lakhs private loan at 11 percent interest.

Loan repayment obligations were structured through annual instalments, resulting in a total annual repayment of approximately Rs. 5.19 lakhs over three years. While the project generated sufficient cash flow to cover these repayments, access to affordable credit remains a key constraint for many farmers.

Investment Appraisal

Investment appraisal indicators such as NPV and IRR provide a useful framework for evaluating financial feasibility. The positive NPV and high IRR observed confirm that protected cultivation projects can generate returns significantly higher than the cost of capital (Annex tables). A payback period of approximately 2.5 years further indicates strong financial performance, assuming stable yields and market prices.

Working Capital Requirements

In addition to fixed investment, protected cultivation requires significant working capital for inputs like seeds, fertilizers, plant protection chemicals, labour, and packaging materials. These expenses are typically acquired well before the farm begins to generate revenue, creating a gap in cash flow. Consequently, timely access to short-term credit becomes critical for farmers to meet operational expenses during the production cycle. Financial institutions and agricultural banks consequently play an important role in supporting the expansion of protected cultivation through tailored credit products.

6.7 DIVERSIFICATION FROM TRADITIONAL CROPS TO PROTECTED CULTIVATION OF HIGH-VALUE HORTICULTURE

Protected cultivation is more and more regarded as a path for agricultural diversification away from traditional cereal-based cropping systems. In many parts of northern India, farmers are moving from wheat–paddy rotations toward high-value horticultural crops such as capsicum, cucumber, zucchini, and exotic vegetables.

Drivers of Diversification

Several factors have contributed to this transition. Stagnating returns from cereal cultivation have encouraged farmers to explore alternative cropping systems with higher profitability. At the same time, increasing urban demand for fresh vegetables has created new market opportunities. The proximity of production zones to urban consumption centres such as Delhi NCR and Lucknow further boosts the feasibility of high-value horticulture by dipping transportation costs and ensuring rapid delivery of perishable produce.

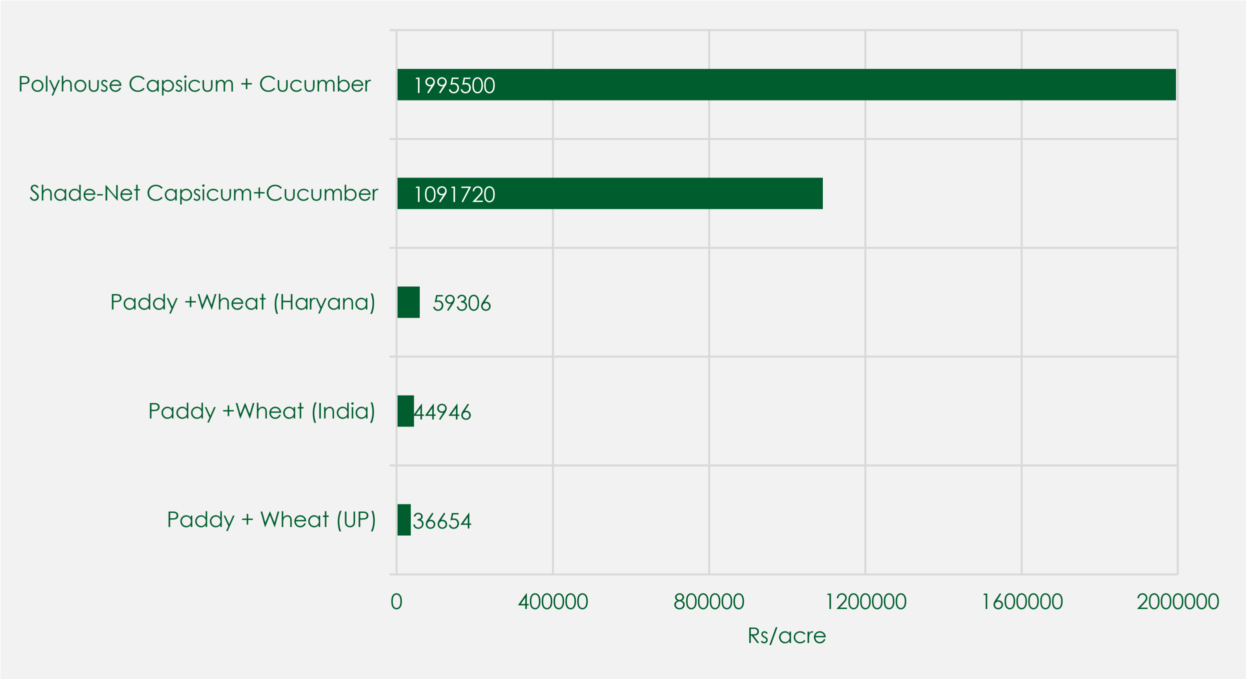
The **Figure 6.2** clearly shows the large profitability advantage of protected cultivation systems over the traditional paddy–wheat cropping rotation. Net returns under polyhouse cultivation of capsicum and cucumber per year are approximately Rs. 19.95 lakhs per acre, which is nearly 30 times higher than the returns from the paddy–wheat system in Haryana (Rs. 59,306 per acre) and more than 50 times higher than the returns from the same rotation in Uttar Pradesh (Rs. 36,654 per acre). The secured MSP based procurement system in Haryana could not ensure as high return as is offered by the protected cultivation. Even relatively lower-cost protected structures such as shade-net houses make considerably higher returns, with net profitability offering about Rs. 10.9 lakhs per acre. These figures signify the strong income potential of high-value horticulture under protected environments.

The huge difference in profitability is principally driven by higher yields, superior quality produce, and proximity to premium market. Besides, protected cultivation allows farmers to produce vegetables during off-season periods when market supply is limited, thereby securing higher prices.

Role of Youth and Agripreneurship

The case of Anushka Jaiswal demonstrates the increasing role of educated youth in transforming agricultural practices. With formal training in protected cultivation and hydroponics, she established a technologically cutting-edge farming enterprise combining polyhouse cultivation, open-field horticulture, and hydroponic production. Such agripreneurs are often more willing to adopt innovative production systems, experiment with new crops, and initiate direct market linkages with retailers and online platforms.

Figure 6.2: Economic Returns: Protected Cultivation vs Traditional Farming



Source: Field Information and Cost of Cultivation data, Kharif and Rabi Report, CACP

Integration with Modern Market Channels

Modern retail platforms and online grocery services have unfolded as important marketing channels for high-quality horticultural produce. These platforms generally pay premium prices for uniform, high-grade produce, though they also impose strict quality and packaging restrictions. As a result, the share of rejected output needs to be channelised through traditional mandi system. In the Lucknow case, approximately 20 percent of production is sold through platforms such as Blinkit and retail outlets like Lulu Mall. These channels provide higher price realization but demand consistent supply and adherence to grading standards. But rest of the output is sold through traders in the mandi network.

Environmental and Sustainability Benefits

Protected cultivation technologies also impart in environmental sustainability through effective resource use. Drip irrigation and fertigation systems minimize water consumption and fertilizer losses, while integrated pest management practices minimize chemical use. Hydroponic systems further enhance resource efficiency by removing soil-based constraints and aiding precise nutrient management.

6.8 CHALLENGES TO SCALABILITY

Despite its economic potential, the large-scale expansion of protected cultivation is facing various structural and institutional challenges.

High Initial Investment

The most significant hindrance in adoption is the high capital requirement for polyhouse infrastructure. Even with government subsidies, farmers must invest significant amounts of their own capital or depend on credit financing. For small and marginal farmers, such investments are often beyond their financial capacity.

Technical Knowledge Gaps

Protected cultivation necessitates specialized knowledge of climate management, fertigation scheduling, pest control, and crop pruning. Many farmers lack access to satisfactory training and extension services, preventing the adoption and performance of these technologies. Strengthening extension networks and launching pilot studies could help address this gap.

Infrastructure and Market Constraints

Efficient marketing of perishable horticultural produce needs reliable cold chain infrastructure, transportation networks, and aggregation mechanisms. In many regions, these systems persist to stay underdeveloped, increasing post-harvest losses and price volatility.

Climatic and Structural Risks

Polyhouse structures are vulnerable to damage from storms, high winds, and dust events. Maintenance and repair costs can reach up to Rs. 2 lakhs annually, significantly affecting profitability. In addition, decreasing groundwater level and increasing salinity in irrigation water pose long-term sustainability challenges.

7 CONCLUDING REMARKS AND POLICY IMPLICATIONS

CONCLUDING REMARKS AND POLICY IMPLICATIONS

The comparative evidence from the case studies underscores both the economic potential and operational complexity of coloured capsicum cultivation under protected environments. While polyhouse systems demonstrate the highest yield gains and income enhancements, their performance is mediated by factors such as capital intensity, technical management capacity, repair and maintenance demands, and access to reliable markets. Karnal's (Haryana) proximity to NCR markets enables farmers to consistently secure higher prices, often reducing the need for platform-based aggregation. However, this advantage is partially offset by high repair costs driven by frequent storms and the seasonal decline in yields during peak winter months, which compresses profitability margins. In contrast, young cultivators in Lucknow (UP) have been more inclined toward digital retail platforms and direct-to-consumer channels, reflecting different market incentives and infrastructure constraints, but these systems also introduce new uncertainties related to demand volatility and platform commissions.

Across sites, the findings illustrate that protected cultivation is not a uniform technological solution, but a production system whose success relies on a calibrated alignment of environmental control, input and maintenance management, marketing strategy, and financial planning. The availability of targeted subsidy schemes has supported adoption, yet long-term sustainability depends on complementary investments in skills training, advisory support, climate risk mitigation, and tailored credit products that match the cash flow characteristics of protected horticulture. Strengthening market linkages, cold-chain infrastructure, and farmer capacity to negotiate value can further reduce exposure to price shocks and transaction-based uncertainties.

Ultimately, the study highlights the importance of context-sensitive policy design, where support measures are adapted to local agro-climatic and market conditions rather than applied uniformly. Protected cultivation holds considerable promise for enhancing farm income, improving resource-use efficiency, and supporting horticultural diversification, but realizing this potential requires a system-level approach one that aligns technological adoption with market access, risk management, and institutional support mechanisms. Such an approach will be essential for scaling protected horticulture as a viable and resilient livelihood strategy within India's evolving agricultural landscape.

Addressing these challenges requires a coordinated policy framework that integrates financial support, technological dissemination, market development, and institutional strengthening. The following policy implications emerge from the analysis.

i. Strengthening Financial Support and Rationalizing Subsidy Design

One of the primary limitations recognized in the adoption of protected cultivation is the high initial investment essential for establishing polyhouses and other controlled-environment structures. Although government schemes such as the MIDH offer subsidies covering up to 50 percent of the installation cost, the actual cost of building polyhouses often surpasses the benchmark estimates used for subsidy calculations. Therefore, farmers are required to mobilize significant capital from their own resources or through credit finance, which discourages adoption among smaller farmers.

Policy reforms should thus emphasise on reviewing subsidy norms to reflect current cost structure of polyhouse structures and associated technologies. A segregated subsidy structure could also be considered, where higher support is provided to small and marginal farmers and FPOs. Furthermore, timely payment of subsidies is critical to ensure that farmers do not suffer from financial strain during the installation period.

ii. Improving Access to Affordable Credit

In addition to subsidy support, access to affordable credit is vital for scaling up protected cultivation. The analysis of case studies highlights that farmer often banks on a combination of personal savings, private loans, and institutional credit to finance polyhouse investments. However, many smallholders face problems in obtaining loans due to collateral requirements, high interest rates, and limited awareness of available financial schemes.

To address this issue, specialized credit products tailored to protected cultivation should be developed by agricultural banks and financial institutions. These credit products should offer longer repayment periods, lower interest rates (current level of interest rate is 11 percent), and flexible repayment timeline aligned with the crop production cycle.

iii. Strengthening Extension Services and Capacity Building

Protected cultivation is a technology-intensive technique that requires specialized knowledge of crop management, fertigation, climate regulation, and pest control. The study divulges that many farmers lack satisfactory technical knowhow to manage polyhouse systems efficiently. This knowledge gap often leads to suboptimal productivity and discourages further adoption.

Strengthening extension services is therefore critical for improving the effectiveness of protected cultivation initiatives. Government interventions, research institutes, and state horticulture departments should expand training programs for farmers on topics such as greenhouse management, integrated pest management, and effective nutrient usage. Demonstration farms and Centres of Excellence established under Indo-Israel/Indo-Dutch cooperation programmes can play a crucial role in distributing best practices and providing hands-on training to farmers.

iv. Developing Efficient Market Linkages and Value Chains

While protected cultivation advances productivity and quality, farmers often face hurdles in marketing their produce due to fragmented supply chains and limited access to organized markets. The study shows that a large share of capsicum output is still marketed through traditional channels involving multiple intermediaries, which decreases the share of the consumer price received by farmers.

Policy interventions should give emphasis on strengthening horticultural value chains through improved aggregation, grading, packaging, and cold storage infrastructure. Promoting FPOs can assist small farmers aggregate their produce and bargain for a better price in wholesale markets. It also minimises transportation cost for smaller farmers. Moreover, developing direct marketing platforms and linking farmers with organized retail chains, supermarkets, and online grocery platforms can improve price realization and diminish dependence on intermediaries.

v. Promoting Infrastructure Development for Horticulture

Post-harvest infrastructure persists to be one of the weakest links in India's horticulture sector. The perishable nature of vegetables such as capsicum makes efficient transportation and storage systems vital for minimizing post-harvest losses. However, many horticulture-producing regions lack adequate cold chain infrastructure, refrigerated transport, and modern storage facilities.

Investment in cold chain logistics, reefer trucks, pack houses, and grading facilities should therefore be prioritized as part of horticulture development strategies. Public–private partnerships can play a critical role in evolving these infrastructure systems, particularly in peri-urban regions where demand for fresh vegetables is fast increasing.

Overall, the findings of this study propose that protected cultivation characterizes a promising roadmap for growing farm income and promoting high-value horticulture in India. However, realizing its full potential needs addressing the structural constraints that currently limit its adoption. A comprehensive policy approach combining financial support, technological capacity building, market development, and infrastructure investment will be vital for scaling up protected cultivation and empowering farmers to benefit from the growing demand for high-value horticultural products.

REFERENCES

Acharya, S. P., Basavaraja, H., Kunnal, L. B., Mahajanashetti, S. B., & Bhat, A. R. (2011). Crop diversification in Karnataka: An economic analysis. Agricultural Economics Research Review, 24(2), 351-358.

Alur, A. S., & Maheswar, D. L. (2018). Crop diversification-a strategy to improve agricultural production. PNASF News, 8, 1-14.

Ansary, S. H., Mudi, N., Barui, K., Chowdhury, A. K., & Gayen, N. (2020). Comparative studies of late planted capsicum (Capsicum annum) for growth and yield under polyhouse and open field conditions as influenced by different growth regulators. J. Pharm. Phytochem, 9(6), 167-170.

Birthal, P. S., Hazrana, J., & Negi, D. S. (2020). Diversification in Indian agriculture towards high value crops: Multilevel determinants and policy implications. Land Use Policy, 91, 104427.

Deshpande, R. S., Mehta, P., & Shah, K. (2007). Crop diversification and agricultural labour in India. Indian Journal of Labour Economics, 50(4), 597-610.

DT, S., Maitra, S., & Sairam, M. (2024). Enhancing Rural Economies with Protected Cultivation Technologies. IJBS, 11(01), 71-79.

Golovaty, J. (2023) "Enhancing Crop Production in Greenhouses with specialised fertilizers"; A special digital issue Greenhouse and Indoor Farming technologies, June 2023

Greenhouse Horticulture in South Korea, Study commissioned by the Netherlands Enterprise Agency. Ministry of Foreign Affairs. 2021.

Gupta, N., & Kannan, E. (2024). Agricultural growth and crop diversification in India: a state-level analysis. Journal of Social and Economic Development, 26(3), 709-733.

Gupta, R. P., & Tewari, S. K. (1985). Factors effecting crop diversification: an empirical analysis. Indian Journal of Agricultural Economics, 40(3), 304-309.

Horticulture Statistics, Department of Agriculture and Farmers' Welfare, MoA&FW, Government of India

Jain, S., Suwalka, C., & Shekhawat, P. S. (2021). Comparative analysis of the economics of crop cultivation under the poly house and open field conditions in Rajasthan. Indian Journal of Economics and Development, 17(1), 222-226.

Joshi, P K and Gulati, A and Birthal, P S (2007) Agricultural Diversification in India. In: Agricultural diversification and smallholders in South Asia. International Food Policy Research Institute, Washington, DC, USA, pp. 219-242. ISBN 8171885519

Joshi, P. K., Gulati, A., Birthal, P. S., & Tewari, L. (2004). Agriculture diversification in South Asia: patterns, determinants and policy implications. Economic and political weekly, 2457-2467.

Kumar, A., Kumar, P., & Sharma, A. N. (2012). Crop diversification in Eastern India: Status and determinants. *Indian Journal of Agricultural Economics*, *67*(4).

Kumar, A., Kumar, P., & Sharma, A. N. (2012). Crop diversification in Eastern India: Status and determinants. Indian Journal of Agricultural Economics, 67(4).

Kumar, C. R., Nayak, C., & Pradhan, A. K. (2024). Status and determinants of crop diversification: evidence from Indian States. Letters in Spatial and Resource Sciences, 17(1), 1.

Kumar, S., & Gupta, S. (2015). Crop diversification towards high-value crops in India: A state level empirical analysis. Agricultural Economics Research Review, 28(2), 339-350.

Kumar, S., Saravaiya, S. N., & Pandey, A. K. (2021). Precision farming and protected cultivation: concepts and applications. CRC Press.

Kumar, S., Saravaiya, S. N., & Pandey, A. K. (2021). *Precision farming and protected cultivation: concepts and applications*. CRC Press.

Ma, X., Dong, J., Gruda, N. S., & Duan, Z. (2023, September). The history of protected horticulture production in China. In *IX South-Eastern Europe Symposium on Vegetables and Potatoes 1391* (pp. 205-210).

Maor, M. (2023) "The Planning, Installation and Adjustment of an Electric Sprayer Apparatus for Spraying Pineapple Grown in Greenhouses"; A special digital issue Greenhouse and Indoor Farming technologies, June 2023.

Meenakshi, & Chattopadhyay, K. S. (2018). An economic analysis of protected cultivation under MIDH in Himalayan states.

Meenakshi, A. E. R. C., & Chattopadhyay, S. K. S. (2017). An Economic Analysis of Protected Cultivation under MIDH in Himalayan States (Consolidated Report). Methodology, 16, 22.

Meir, M(2023) "DryGair-The Dehumidification Technology Reducing Horticulture's Energy Footprint", A special digital issue Greenhouse and Indoor Farming technologies, June 2023

Ming He, Xiuchao Wan, Hanlin Liu, Tianyang Xia, Zhanran Gong, Yiming Li, Xingan Liu, Tianlai Li,Theory and application of sustainable energy-efficient solar greenhouse in China, Energy Conversion and Management,]Volume 325, 2025, ISSN 0196-8904, https://doi.org/10.1016/j.enconman.2024.119394

Nass, T. (2010). Netherlands-Sustainable horticulture crop production. Dept. of Horticultural Science, University of Minnesota.

Neogi, S., & Ghosh, B. K. (2022). Evaluation of crop diversification on Indian farming practices: A panel regression approach. Sustainability, 14(24), 16861.

Ode, Yuzo (2020) Current status and challenges of Japanese greenhouse horticulture: Latest developments in smart agriculture and regional energy utilization; Japan Greenhouse Horticulture Association

Pachiyappan, P., Kumar, P., Reddy, K. V., Kumar, K. N. R., Konduru, S., Paramesh, V., ... & Niranjan, S. (2022). Protected cultivation of horticultural crops as a livelihood opportunity in western India: An economic assessment. *Sustainability*, *14*(12), 7430.

Pattanayak, A., Srinivasan, M., & Kumar, K. K. (2023). Crop diversity and resilience to droughts: evidence from Indian agriculture. Review of Development and Change, 28(2), 166-188.

Pingali, P. L., & Rosegrant, M. W. (1995). Agricultural commercialization and diversification: processes and policies. Food policy, 20(3), 171-185.

Prakash, P., Kumar, P., Kishore, P., Jaganathan, D., & Immanuel, S. (2021). Economic feasibility of polyhouse establishment with and without government subsidy support: A case of gerbera cultivation in Maharashtra, India. India Journal of Modern Agriculture, 10, 727-735.

Priyadarshini, P., & Abhilash, P. C. (2020). Policy recommendations for enabling transition towards sustainable agriculture in India. Land use policy, 96, 104718.

Rani, N., Tiwari, D., Kaur, G., & Sharma, D. (2024). Enhancing Agricultural Productivity: A Comparative Study of Vegetable Cultivation under Polyhouse and Open Field Conditions in Punjab, India. Journal of Scientific Research and Reports, 30(7), 166-174.

Renbomo Ngullie, R. N., & Biswas, P. K. (2016). Performance of capsicum under protected and open field conditions under Mokokchung district of Nagaland.

Singh, A.K., Dhar, S., Perinban, S., Singh, V., Kumar, M. and Kumar, A. (2016). Standardization of production technology for hybrid coloured capsicum (Capsicum annuum var grossum) based on yield and economic benefit under different protected structures in plains of India. Indian Journal of Agricultural Sciences, 86(7): 910-5.

Singh, B., & Solanki, R. (2014). Protected cultivation technologies for vegetable cultivation under changing climatic conditions. *Climate change: the principles and applications in horticultural science. CRC Press, Taylor & Francis Group, Boca Raton*, 106-114.

Singh, B., Singh, B., Kumar, B., & Chadha, L. M. (2007). Working group report on development of protected cultivation in Haryana. Government of Haryana, Haryana Kisan Ayog CCS Haryana Agricultural University Campus, Hisar.

Smith, J. C., Ghosh, A., & Hijmans, R. J. (2019). Agricultural intensification was associated with crop diversification in India (1947-2014). PloS one, 14(12), e0225555.

Smith, J. C., Ghosh, A., & Hijmans, R. J. (2019). Agricultural intensification was associated with crop diversification in India (1947-2014). PloS one, 14(12), e0225555.

Thakur, P., Mehta, P., Lal, P., Chaudhary, R., Pani, S. K., Singh, A. G., ... & Sharma, P. (2024). Agricultural produce supply chain network of capsicum: empirical evidence from India. Economies, 12(1), 24.

Tong, X., Zhang, X., Fensholt, R., Jensen, P. R. D., Li, S., Larsen, M. N., ... & Brandt, M. (2024). Global area boom for greenhouse cultivation revealed by satellite mapping. Nature Food, 5(6), 513-523.

Tüzel, Y., & Katsoulas, N. (2017, September). Protected cultivation in Mediterranean region. In I International Conference and X National Horticultural Science Congress of Iran (IrHC2017) 1315 (pp. 323-334).

Victoria, N. G., van der Valk, O., & Elings, A. (2011). Mexican protected horticulture. Wageningen UR Greenhouse Horticulture, 2011: 31.

Vyas, V. S. (1996). Diversification in agriculture: concept, rationale and approaches. Indian Journal of Agricultural Economics, 51(4), 636.

Wu, F., Guan, Z., & Huang, K. M. (2022). Protected Agriculture in Mexico: FE1124, 12/2022. EDIS, 2022(6).

ANNEXURE

Case 1: Estimation of Net Present Value (NPV) for Polyhouse Cultivation of Anushka Jaiswal

Initial investment = Rs.35 lakhs

Annual net return = Rs.19.5 lakhs

Time period = 10 years

Discount rate = 10%

Discount Factor $(DF_t) = \frac{1}{(1.1)^t}$

Year	Cash Flow (₹Rs.lakhs)	Discount Factor	Present Value
1	19.5	0.909	17.73
2	19.5	0.826	16.11
3	19.5	0.751	14.65
4	19.5	0.683	13.32
5	19.5	0.621	12.11
6	19.5	0.564	11
7	19.5	0.513	10
8	19.5	0.467	9.11
9	19.5	0.424	8.27
10	19.5	0.386	7.53

Total PV= $\Sigma Present\ Values$ = Rs.119.83 lakhs

NPV= 119.83 lakhs –35 lakhs= Rs. 84.8 lakhs

0=NPV= $\Sigma_{t=1}^{T} \frac{CF_t}{(1+IRR)^t}$ - C_0

CF_t=Net Cash Flow at period t

C_0= Initial capital Investment

IRR=Internal rate of return

t= time period

Solving this IRR= 54 percent

If return is calculated taking annualised fixed cost into account:

Net return=Rs. 16 lakhs

Following same methodology,

NPV=Rs. 63 lakhs

IRR= 44 percent

Case 2: Estimation of Net Present Value (NPV) for Polyhouse Cultivation of Shubham Diwedi

Initial investment = Rs.24.9 lakhs

Annual net return = Rs.14.4 lakhs

Time period = 10 years

Discount rate = 10%

Discount Factor (DF_t) = $\frac{1}{(1.1)^t}$

Year	Cash Flow (₹ lakhs)	Discount Factor	Present Value (₹ lakhs)
1	14.4	0.909	13.09
2	14.4	0.826	11.89
3	14.4	0.751	10.81
4	14.4	0.683	9.84
5	14.4	0.621	8.94
6	14.4	0.564	8.12
7	14.4	0.513	7.39
8	14.4	0.467	6.72
9	14.4	0.424	6.1
10	14.4	0.386	5.56

Total PV= $\Sigma Present\ Values$ = Rs.88.46 lakhs

NPV= 88.46 lakhs – 24.9lakhs= Rs. 63.6lakhss

0=NPV= $\Sigma_{t=1}^{T} \frac{CF_t}{(1+IRR)^t}$ - C_0

CF_t=Net Cash Flow at period t

C_0= Initial capital Investment

IRR=Internal rate of return

t= time period

Solving this IRR= 55 percent

If return is calculated taking annualised fixed cost into account:

Net return=Rs. 11.9 lakhs

Following same methodology,

NPV=Rs. 48 lakhs

IRR= 46 percent

Case 3: Estimation of Net Present Value (NPV) for Shade Net house Pawan Kumar Singh

Initial investment = Rs.10 lakhs

Annual net return = Rs.8.9 lakhs

Time period = 10 years

Discount rate = 10%

Discount Factor (DF_t) = $\frac{1}{(1.1)^t}$

Year	Cash Flow (Rs. lakhs)	Discount Factor	Present Value (₹ lakhs)
1	8.917	0.909	8.1
2	8.917	0.826	7.37
3	8.917	0.751	6.7
4	8.917	0.683	6.09
5	8.917	0.621	5.54
6	8.917	0.564	5.03
7	8.917	0.513	4.57
8	8.917	0.467	4.16
9	8.917	0.424	3.78
10	8.917	0.386	3.44

Total PV= $\Sigma Present\ Values$ = Rs.54.78 lakhs

NPV= 54.78 lakhs – 10 lakhs= Rs.44.78 lakhs

0=NPV= $\Sigma_{t=1}^{T} \frac{CF_t}{(1+IRR)^t}$ - C_0

CF_t=Net Cash Flow at period t

C_0= Initial capital Investment

IRR=Internal rate of return

t= time period

Solving this IRR= 89 percent

If return is calculated taking annualised fixed cost into account:

Net return=Rs. 7.92 lakhs

Following same methodology,

NPV=Rs. 38.6 lakhs

IRR= 79 percent

Indian Council for Research on International Economic Relations (ICRIER)
Our Offices:
4th Floor, Core 6A, India Habitat Centre, Lodhi Road, New Delhi-110003
The Isher Building, Plot No. 16-17, Pushp Vihar, Institutional Area, Sector 6, New Delhi-110017
O: +91 11 43112400, F: +91 11 24620180 | W: www.icrier.org | E: info@icrier.res.in