Perspectives, Future Challenges and Strategic Options in Protected Cultivation in India

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Protected cultivation has emerged as one of the most promising technologies for enhancing productivity, quality, profitability, and resource-use efficiency in horticultural crops. Over the last few decades, it has proven to be an effective technological intervention for managing both biotic and abiotic stresses that commonly limit crop production under open-field conditions. By creating a controlled or partially controlled microclimate around crops, protected cultivation enables higher yields, better quality produce, offseason production, efficient utilization of water and nutrients, and improved protection against adverse environmental conditions.

Globally, the adoption of protected cultivation technologies has expanded rapidly, particularly in countries surrounding the Mediterranean region and in China. Various forms of protected cultivation such as mulching, plastic low tunnels, walk-in tunnels, insect-proof net houses, shade net houses, naturally ventilated greenhouses, and climate-controlled greenhouses are now widely used for cultivation of vegetables, flowers, fruits, and nursery crops. Among all countries, China has emerged as the global leader in protected cultivation, with nearly 3.5 million hectares under different forms of protected horticulture. More than 95% of this area is devoted to commercial vegetable cultivation and hybrid seed production.

India has also witnessed considerable growth in protected cultivation during the last two decades. Presently, more than 160,000 hectares are under various forms of protected structures, largely promoted through government schemes such as the Mission for Integrated Development of Horticulture (MIDH), National Horticulture Mission (NHM), National Horticulture Board (NHB), Rashtriya Krishi Vikas Yojana (RKVY), and state horticulture missions. However, unlike China, where protected cultivation evolved through strong research–industry–farmer integration, the Indian experience has been mixed because many technologies were initially adopted without sufficient adaptation to diverse agro-climatic conditions.

India is characterized by highly variable climatic conditions ranging from arid and semi-arid regions to humid tropical and temperate ecosystems. Consequently, protected structures designed for European

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climatic conditions often failed to perform efficiently under Indian environments, particularly in the hot plains of northern and western India. In contrast, relatively milder regions such as Bengaluru, Pune, and parts of Himachal Pradesh and Uttarakhand achieved better success due to more suitable climatic conditions. Over time, research conducted by institutions such as the Indian Agricultural Research Institute, ICAR institutes, and State Agricultural Universities has clearly demonstrated that region-specific protected structures and crop production modules are essential for achieving sustainability and profitability.

Protected cultivation has enormous potential in India not only for increasing productivity but also for generating rural employment, promoting agri-entrepreneurship, and strengthening nutritional and economic security. The technology offers significant opportunities for educated rural youth, women entrepreneurs, Farmer Producer Organizations (FPOs), and peri-urban farming systems. Under the emerging framework of organized retail, export-oriented horticulture, and increasing consumer demand for safe and high-quality produce, protected cultivation can substantially enhance farmers' income through production of offseason vegetables, cut flowers, high-value nursery crops, and hybrid seeds.

High-value crops such as coloured capsicum, parthenocarpic cucumber, cherry tomato, tomato, lettuce, exotic leafy vegetables, gerbera, carnation, chrysanthemum, and roses have shown tremendous potential under protected conditions. Similarly, insect-proof net houses and low-cost structures are becoming increasingly important for raising healthy seedlings, hybrid seed production, and cultivation of virus-sensitive crops. Protected cultivation also facilitates higher water-use efficiency through drip irrigation and fertigation, reduces indiscriminate pesticide application, and supports Good Agricultural Practices (GAP) and residue-free production systems.

Despite these advantages, several challenges continue to limit the large-scale adoption and sustainability of protected cultivation technologies in India.

MAJOR CHALLENGES IN PROTECTED CULTIVATION IN INDIA

1. Lack of Region-Specific Protected Structure Designs

One of the major limitations is the non-availability of scientifically validated region-specific designs suitable for different agro-climatic zones. Structures developed for temperate climates often fail under extreme Indian conditions such as high temperatures, strong winds, heavy rains, and dust storms.

2. Poor Quality Fabrication

The fabrication of protected structures has increasingly become commercially driven, often compromising structural quality. Use of substandard galvanized pipes, cladding materials, and poor engineering practices significantly reduces the life and effectiveness of structures.

3. Shortage of Skilled Human Resources

India faces a serious shortage of trained professionals for design, installation, maintenance, and crop management under protected cultivation systems. Large-scale skill development initiatives are still lacking.

4. Limited Availability of Suitable Crop Varieties

Most varieties currently available are imported hybrids with high seed costs. There is insufficient development of public-sector varieties specifically bred for protected cultivation conditions.

5. Weak Marketing and Value Chain Integration

Many growers adopt protected cultivation without proper market assessment, resulting in oversupply and poor price realization. Lack of organized marketing, cold chain infrastructure, and processing facilities further aggravates the problem.

6. Increasing Soil-Borne Diseases

Continuous cultivation under protected environments has led to serious issues related to Fusarium wilt, root-knot nematodes, salinity, and soil fatigue.

7. Non-Availability of Disease-Free Planting Material

The absence of certified disease-free and virus-free planting material remains a major bottleneck in vegetables, flowers, and fruit crops.

8. Energy and Water Constraints

Reliable electricity and quality irrigation water are critical for successful protected cultivation. In many regions, inadequate infrastructure limits sustainability.

STRATEGIC OPTIONS AND FUTURE DIRECTIONS FOR INDIA

The future of protected cultivation in India is highly promising if implemented with scientific planning, regional customization, and market integration. The following strategic interventions can accelerate sustainable adoption:

PROMOTION OF LOW-COST AND CLIMATE-RESPONSIVE STRUCTURES

Instead of promoting expensive imported greenhouse models, emphasis should be placed on low-cost naturally ventilated structures, insect-proof net houses, shade net houses, and walk-in tunnels suitable for Indian conditions.

CLUSTER-BASED DEVELOPMENT APPROACH

Protected cultivation should be promoted in cluster mode, especially in peri-urban regions near major consumption centres. Such clusters should be integrated with input hubs, cold chains, grading facilities, and market linkages.

STRENGTHENING NURSERY AND SEEDLING INDUSTRY

Commercial plug-tray nurseries and protected nurseries for production of healthy seedlings can emerge as major agri-enterprises. Disease-free planting material production must become a national priority.

PROTECTED CULTIVATION FOR HYBRID SEED PRODUCTION

India has immense potential to become a global hub for hybrid vegetable seed production under protected structures because of favorable climatic diversity and comparatively lower production costs.

SKILL DEVELOPMENT AND ENTREPRENEURSHIP

Large-scale capacity-building programmes should be launched for rural youth in two domains:

- Design, fabrication, and maintenance of protected structures
- Crop production and agribusiness management under protected systems

The Chinese model of skill-oriented protected horticulture development may provide useful lessons for India.

INTEGRATION WITH SOLAR ENERGY AND RAINWATER HARVESTING

Solar-powered irrigation and climate management systems should be integrated with protected cultivation units. Similarly, all protected cultivation clusters should be linked with rainwater harvesting infrastructure.

MECHANIZATION AND AUTOMATION

Promotion of raised bed makers, mulch laying machines, tunnel-making equipment, fertigation systems, and automation tools can improve efficiency and reduce labour dependency.

STRENGTHENING RESEARCH AND POLICY SUPPORT FOR EFFECTIVE & ECONOMICALLY SUSTAINABLE SYSTEM

- Region-specific crop production protocols
- Indigenous region-specific greenhouse designs
- Public-sector Varieties or Hybrids development for Protected conditions
- Seed production of Public-sector developed varieties suitable for Protected conditions
- Soil health management technologies
- Biological control of biotic stresses & pollination management under protected Conditions
- Integrated pest and disease management systems only limited to some problems
- Artificial intelligence and sensor-based climate management

Government support should gradually shift from merely subsidizing structures to supporting complete production systems, market integration, and entrepreneurship development.

CONCLUSION

Protected cultivation is no longer merely an alternative production technology; it is becoming an essential component of climate-resilient and high-value horticulture in India. In the context of shrinking landholdings, water scarcity, climate variability, rising consumer demand for safe food, and increasing opportunities in organized retail and exports, protected cultivation offers a transformative pathway for sustainable horticultural intensification.

However, the long-term success of the technology depends on scientific region-specific interventions, strong research–extension–industry linkages, quality infrastructure, market-driven production planning, and large-scale skill development. The future growth of protected cultivation in India should focus not only on increasing the number of structures but also on developing economically viable, technically sound, environmentally sustainable, and farmer-centric production systems.

If implemented strategically, protected cultivation can significantly contribute to doubling farmers' income, generating rural employment, strengthening nutritional security, and positioning India as a global leader in high-value horticultural production and hybrid seed systems.