

Review Article

Open Access

Advancements and innovations in protected cultivation for horticultural and floricultural crops: A Comprehensive Review

Deepika Bansal^{1*}, Hitesh², Arvind Malik², AbhishekOjha³

¹Department of Horticulture (FLS), CCS Haryana Agricultural University, Hisar, Haryana, India. 125004

²Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar, Haryana, India. 125004

ABSTRACT

The practice of protected cultivation of horticultural crops has become increasingly important in contemporary agriculture, providing advantages that include higher yields, improved quality and defense against pests and unfavorable weather. This review aims to evaluate current protected cultivation practices and investigate their potential in horticulture and floriculture. The examination begins by reviewing the various protected production structures, such as greenhouses, high tunnels and shade houses, detailing their structural benefits and environmental limitations. The importance of protected farming in addressing global food security issues is emphasized, particularly its role in maintaining crop output year-round. Furthermore, this review examines the impact of climate control and the optimization of environmental parameters—including temperature, humidity and carbon dioxide levels—on crop morphogenesis. The application of cutting-edge technologies, such as aeroponics, hydroponics and vertical farming, is critically analyzed, highlighting their potential to maximize output while consuming minimal resources. However, implementing these systems presents profound systemic challenges, primarily the substantial initial capital required, the high energy consumption of climate regulation in regions with irregular electricity, and the risk of rapid disease spread in enclosed spaces. Adapting this advanced infrastructure to be economically scalable for smallholder farmers across diverse agro-climatic zones remains a critical bottleneck. The study also identifies major difficulties and limitations associated with adopting protected cultivation, such as high energy requirements and financial constraints and outlines critical research gaps in sustainable infrastructure. Finally, the investigation explores future perspectives, including the application of artificial intelligence and precision agriculture methods, which could lead to increased yields by further optimizing resource utilization.

Keywords: Protected cultivation, Floriculture, Greenhouse technology, Precision agriculture, Sustainable horticulture, Aeroponics, Hydroponics, Agrivoltaics, Climate control.

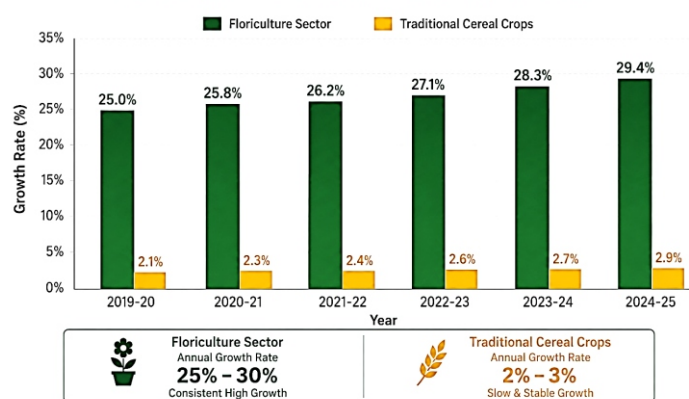
1. Introduction

India's integration into global markets and its economic liberalization have created immense opportunities for the export of premium horticultural crops, alongside a rapidly expanding domestic market [31, 63]. To satisfy the expectations of quality-conscious consumers, agricultural systems must simultaneously enhance crop yield and quality [53]. While basic elements such as planting material and routine cultural practices can be managed in open fields, the precise environmental regulation required for optimal growth is only possible in enclosed settings [7, 28, 35].

Consequently, there is a pressing need for innovative production technologies that align high yields with strict market quality parameters [24]. Protected cultivation, widely known as greenhouse technology, fulfills this requirement by artificially tailoring the microclimate surrounding the plant to its specific developmental needs.

This approach holds exceptional promise for the floriculture sector, which exhibits an annual growth rate of 25–30% and has the potential to generate significantly higher foreign revenue than traditional cereal crops [63]. As illustrated in Figure 1, consistent high growth in the floriculture sector underscores the economic necessity of protected structures.

ANNUAL GROWTH COMPARISON FLORICULTURE SECTOR vs TRADITIONAL CEREAL CROPS



*Corresponding Author: **Deepika Bansal**
Email Address: deepikabansal1710@gmail.com

DOI: <https://doi.org/10.21276/AATCCReview.2026.14.03.01>

© 2026 by the authors. The license of AATCC Review. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

Figure 1: Annual growth rate comparison between the floriculture sector and traditional cereal crops

By safeguarding plants against unpredictable weather hazards and pest infestations, regulated environments guarantee a reliable, consistent and high-quality harvest [21, 53 and 59]. The transition to protected environments provides substantial physiological and financial advantages, promoting faster maturity and improving crucial floral characteristics. Because this method can amplify yields four to five times compared to conventional farming [53], commercial floriculture heavily relies on these structures for export markets [31, 34]. The primary objective of this review is to synthesize recent literature on protected cultivation, critically analyze current technological advancements and identify knowledge gaps to guide future horticultural research.

2. Literature Review

The existing literature extensively covers the structural designs and environmental manipulations required for protected cultivation. This section categorizes the fundamental components and major commercial applications identified in recent studies.

2.1 Types of Protected Cultivation Structures

Depending on agro-climatic conditions and resource availability, growers utilize a variety of protective structures (Figure 2 and Figure 3) [21, 26, 54].

- **Greenhouses:** Transparent, framed, or inflatable structures used to grow crops in a controlled environment [14, 50]. They can be classified by shape (Lean-to, Even Span, Uneven Span, Ridge and Furrow, Saw Tooth, Quonset) or construction material (Wooden Frame, Pipe Frame, Truss Frame). Cost considerations divide them into low-cost (bamboo/wood with UV film), medium-cost (galvanized iron with semi-automatic controls) and high-cost (aluminum/iron frames with computerized controls) structures.

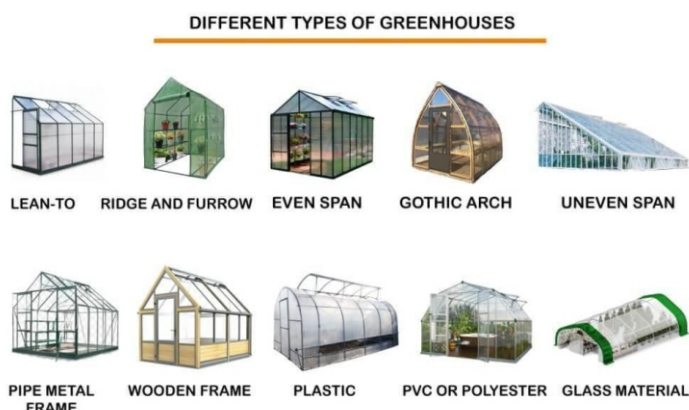


Figure 2: Classification of greenhouse structures based on shape and construction design.

- **Cladding Materials:** Polythene is an affordable cladding material, while UV-stabilized fiberglass and polycarbonate panels act as durable alternatives. Linear low-density polyethylene (LLDPE) and low-density polyethylene (LDPE) have a three to four-year lifespan when treated with UV stabilizers [40].
- **Alternative Structures:** Shade net houses provide filtered sunlight for shade-loving plants, utilizing materials like commercial plastic nets with specific cut-out percentages (e.g., 40%, 60%, 80%). Lath houses, cold frames and hot beds provide seasonal protection and early germination benefits [56].



Figure 3: Structural and functional comparison of high-tech glasshouses, standard polyhouses and shade net houses

2.2 Environmental Factors in Protected Cultivation

The optimization of environmental parameters (Figure 4) is essential for preventing disease and maximizing yield [50, 54, 56].



Figure 4: Schematic representation of automated environmental control systems within a modern greenhouse

- **Temperature and Humidity:** Optimal temperatures (15–30°C for ornamentals) and humidity (50–80%) are critical [50]. Insufficient humidity causes dehydration, while excess promotes fungal diseases [55].
- **Light Intensity and Photoperiod:** Enhancing light with LED systems encourages compact growth [58]. Photoperiod manipulation is crop-specific; for instance, petunias require long days, while chrysanthemums require short days [25, 66]. Red and blue light wavelengths are notably effective for improving photosynthesis [37, 42].
- **Carbon Dioxide Enrichment:** Raising carbon dioxide levels (700–1,500 ppm) increases plant productivity and water-use efficiency [7, 33, 45, 68].
- **Nutrient and Water Management:** Drip irrigation saves 30–70% on water while achieving high efficiency [9, 30]. Precise macronutrient and micronutrient delivery via fertigation ensures effective absorption when substrate pH is maintained between 5.5 and 6.5 [51, 57].

2.3 Major Commercial Flower Crops

Protected cultivation is predominantly utilized for high-value ornamentals (Figure 5) [61].



Figure 5: Major commercial high-value floricultural crops cultivated in protected environments

A critical summary of their propagation and environmental requirements is provided in Table 1.

Table 1: Summary of Requirements for Major Commercial Flower Crops under Protected Cultivation

Crop	Primary Propagation Method	Optimal Substrate / Soil pH	Key Environmental / Management Factors
Rose	Budding / Top-grafting	5.5 – 6.5 (Loamy / Soilless)	Humidity 50–60%; Drip fertigation (N, P, K, Mg)
Carnation	Stem cuttings (IBA/NAA)	5.5 – 6.5 (Well-drained)	EC 1.2–1.7 mS/cm; Strict ventilation
Gerbera	Tissue culture / Cuttings	5.5 – 6.5 (Slightly acidic)	Biological control of mites; Precise fertigation
Orchid	Tissue culture / Seed	Bark chips, coir, sphagnum	High humidity (70–80%); Symbiotic fungi reliance
Chrysanthemum	Terminal cuttings / Tissue	6.5 (Sandy loam / Perlite)	Strict photoperiod control; Cold storage post-harvest

(Data synthesized from: 8, 19, 23, 49)

3. Current Advances

Recent literature indicates a shift toward integrating high-technology systems with traditional protected cultivation to enhance sustainability and yield [59].

3.1 Automation and Smart Greenhouse Technology

Combining robotics, the Internet of Things (IoT) and Artificial Intelligence (AI) facilitates the real-time monitoring of temperature, humidity and soil moisture [3]. Predictive analytics modifies environmental conditions, while robotics automates planting, harvesting and irrigation [38, 41].

3.2 Hydroponics and Aeroponics

Soilless cultivation techniques offer exact control over growth conditions (Figure 6). Aeroponics suspends roots in misted air, while hydroponics grows plants in nutrient-rich water. Both are increasingly enhanced by fuzzy logic-based IoT systems, significantly reducing water usage compared to soil-based methods [69].

3.3 Greenhouse Agrivoltaics

Incorporating photovoltaic (PV) panels in greenhouse farming presents a viable method to modify microclimates, offset high energy consumption and increase overall farm sustainability [17]. Agrivoltaic systems allow for dual land use, balancing energy production with horticultural output [14].

3.4 Biostimulants and Organic Cultivation

The reliance on synthetic inputs is being mitigated by the use of phytohormones and biostimulants, such as *Pseudomonas entomophila* PE3, which increase stress tolerance and yield [18, 44].

4. Challenges and Research Gaps

While protected cultivation offers numerous benefits, critical analysis reveals several systemic challenges and significant gaps in current research.

Current Challenges:

- **Financial Constraints:** The high initial capital required for infrastructure, coupled with ongoing maintenance expenses and market volatility, poses a barrier to smallholder farmers [6, 21].
- **Energy Consumption:** Advanced climate regulation technology demands high, consistent energy input, which is particularly challenging in developing regions with irregular electricity supply [26].
- **Biotic Stresses in Enclosed Environments:** Diseases can spread rapidly in controlled spaces. Furthermore, the exclusion of natural pollinators necessitates artificial pollination, which increases labor costs [1, 12, 15].

Identified Research Gaps:

1. Region-Specific Cost Models: Most literature focuses on high-tech glasshouses suitable for temperate zones. There is a lack of comprehensive studies on optimizing low-to-medium cost polyhouses specifically for tropical and sub-tropical microclimates [28].

2. Scalability of AI and IoT: While smart greenhouses are proven in experimental settings, research addressing the economic scalability and user-friendly adoption of these technologies for rural farmers remains sparse [3].

3. Long-term Environmental Impact of Cladding: The degradation and disposal of polyethylene films present an ecological issue that requires further investigation into biodegradable or fully recyclable cladding alternatives [40].

5. Future Perspectives

The future of protected cultivation relies on harmonizing technological innovation with ecological sustainability [7, 34]. Developing polyhouse designs tailored to localized climatic requirements will be essential for boosting efficiency. Furthermore, making advanced UV-stabilized plastic sheets and shading nets more accessible to marginal farmers will improve the widespread robustness of these systems [21].

Future research must prioritize breeding plant varieties specifically genetically tailored specifically for enclosed environments (e.g., varieties that require less ventilation or have higher resistance to greenhouse-specific pathogens) [6]. The continued integration of AI-driven precision agriculture and renewable energy (agrivoltaics) will be the primary driver in overcoming current energy and labor constraints, maximizing resource efficiency and ensuring the economic viability of floriculture in the coming decades [34, 61].

6. Conclusion

Protected cultivation offers an essential, modern approach for the floriculture and horticulture industries by providing substantial advantages in crop yield, quality and environmental control. It successfully mitigates the unpredictability of open-field farming, ensuring year-round production of premium crops. Despite challenges such as high initial costs, high energy demands and the necessity for skilled labor, technological advancements like AI, IoT, hydroponics and the use of biostimulants are making protected agriculture increasingly resilient. By addressing existing research gaps and tailoring infrastructure to regional needs, the sector can sustainably meet both domestic and international market demands well into the future.

Acknowledgements

The authors would like to acknowledge the support of the Department of Horticulture at CCS Haryana Agricultural University for providing the necessary resources to conduct this comprehensive review.

Authors Contribution

Deepika Bansal conceptualized the review, conducted the primary literature search, drafted the initial manuscript and revised the final version for submission. Hitesh assisted in data synthesis, literature screening and writing the sections on environmental parameters and commercial crop applications. Arvind Malik contributed to the analysis of structural materials, cladding technologies, and agro textiles and helped draft the technological advancements section. Abhishek Ojha provided a critical review of the manuscript, assisted with formatting and contributed to the discussion on challenges and future research gaps. All authors read, reviewed and approved the final manuscript.

Conflict of interest

The authors declare no conflict of interest.

References

1. Abraham, V. (2012). Management of serpentine leaf miner in protected cultivation. *Journal of Applied Entomology*, 45(2), 112–118.
2. Anderson, J. and Smith, R. (2021). Harvesting techniques for orchids. *Journal of Horticultural Science*, 45(3), 123–130.
3. Ardiansah, I., Bafdal, N., Suryadi, E. and Bono, A. (2022). Greenhouse monitoring and automation using Arduino: A review on precision farming and Internet of Things (IoT). *International Journal on Advanced Science, Engineering and Information Technology*, 12(1), 396–3850.
4. Bala, M. and Singh, K. (2013). Effect of different potting media for pot mum production in chrysanthemum grown under open and polyhouse conditions. *Journal of Ornamental Horticulture*, 16(1-2), 35–39.
5. Bhagat, R. M., Shekhawat, K. S. and Pandya, H. (2020). Effects of different nutrient management techniques on the growth and yield of carnation. *Horticultural Science*, 47(3), 49–55.
6. Bhanwaria, S. and Vatta, L. (2021). Protection cultivation: Need, status and challenges. *Just Agriculture*.
7. Bhattacharya, N. and Bhattacharya, S. (2020). *Greenhouse technology and its applications in sustainable agriculture*. Springer.
8. Bisht, S., Sharma, A. and Singh, R. (2022). Evaluation of rose rootstocks for high-density planting under protected conditions. *Indian Journal of Horticulture*, 79(2), 145–152.
9. Brahmabhatt, R., Patel, P. and Raval, D. (2019). Soil and irrigation management in polyhouse carnation cultivation. *Journal of Soil Science and Plant Nutrition*, 16(2), 25–33.
10. Brown, T., Chen, L. and Davis, M. (2023). Propagation methods for orchids: A review. *Orchid Research Journal*, 12(1), 45–58.
11. Carter, P. and Lopez, A. (2021). Nutrient management in orchid cultivation. *Plant Nutrition Studies*, 19(4), 201–210.
12. Chandel, R. S., Sharma, P. L., Verma, S. C., Shah, M. A. and Gavkare, O. (2017). Functional response of *Homonia dimidiata* (Fab.) to melon aphid, *Aphis gossypii* Glover under laboratory conditions. *Phytoparasitica*, 45, 373–379.
13. Chen, Y., Kim, S. and Patel, R. (2020). Timing of orchid harvesting: Effects on quality. *Horticulture International*, 30(2), 87–95.
14. Chimankare, R. V., Das, S., Kaur, K. and Magare, D. (2023). A review study on the design and control of optimised greenhouse environments. *Journal of Tropical Ecology*, 39, Article e26.

15. Cloyd, R. A. (2013). Pesticide compatibility with natural enemies for pest management in greenhouses. *Journal of Economic Entomology*, 106(4), 1590–1600.
16. Davis, L. (2020). Mycorrhizal associations in orchids. *Mycology Today*, 15(2), 67–72.
17. Ezzaeri, K., Fatnassi, H., Bouharroud, R., Gourdo, L., Bazgaou, A., Wifaya, A. and Demrati, H. (2018). The effect of photovoltaic panels on the microclimate and on the tomato production under photovoltaic Canarian greenhouses. *Solar Energy*, 173, 1126–1134.
18. Fatima, T. and Arora, N. K. (2021). Pseudomonas entomophila PE3 and its exopolysaccharides as biostimulants for enhancing growth, yield and tolerance responses of sunflower under saline conditions. *Microbiological Research*, 244, 126671.
19. Ganesh, S., Kannan, M., Jawaharlal, M., Arulmozhiyan, R. and Jeyakumar, P. (2015). Standardization of growing medium for cut chrysanthemum (*Dendranthema grandiflora* Tzvelev) cv. Amalfi under protected conditions. *Journal of Ornamental Horticulture*, 18(1-2), 48–55.
20. Garcia, M. and Thompson, J. (2021). Advances in orchid tissue culture techniques. *Plant Cell Reports*, 40(5), 789–800.
21. Ghanghas, B. S., Mukteshwar, R. and Shehrawat, P. S. (2017). Protected cultivation (polyhouse) in Haryana: Problems and prospects. *Indian Journal of Extension Education*, 53(1), 104–110.
22. Gupta, M. S., Joshi, R. and Sharma, A. (2004). Standardization of growing media under protected environment for Gerbera in Himachal Pradesh. *Horticultural Science*, 23(2), 98–103.
23. Gupta, R., Meena, S. and Singh, N. (2019). Effects of different substrates and pH levels on carnation growth in polyhouses. *Journal of Agricultural Science*, 72(4), 135–142.
24. Jadhav, S. B., Thorat, N. V., Katwate, S. M. and Kakade, D. S. (2020). Effect of polyhouse cultivation on yield of tuberose genotypes. *International Journal of Current Microbiology and Applied Sciences*, 9(12), 1234–1240.
25. Jangid, K., Patel, P. and Sharma, R. (2020). Influence of photoperiod on flowering regulation in ornamental plants. *Journal of Horticultural Sciences*, 14(3), 210–225.
26. Jayashree, E., Suresh, J. and Suresh, K. (2023). Protected cultivation in tropical tuber crops – A review. *Journal of Root Crops*, 49(1), 1–10.
27. Jayavalli, R., Indu Rani, C. and Sabir Ahamed, A. (2024). Performance assessment of polyhouse cultivation of chrysanthemum under sodic soils. *Pest Management in Horticultural Ecosystems*, 30(1).
28. Jensen, M. H. (2002). Controlled environment agriculture in deserts, tropics and temperate regions—A world review. *Acta Horticulturae*, 578, 19–25.
29. Johnson, H. and Lee, K. (2021). Biological control in orchid pest management. *Entomological Society Journal*, 28(3), 150–159.
30. Kachwaya, H. M., Narmada, J. and Patel, A. (2024). Fertigation and irrigation systems for protected cultivation: A review. *International Journal of Horticultural Science*, 58(1), 25–30.
31. Kaur, P. and Dubey, R. K. (2019). Present status and future prospects of protected cultivation in India. *Agricultural Reviews*, 40(3), 180–188.
32. Kim, J. and Park, E. (2022). Irrigation strategies for optimal orchid growth. *Journal of Agricultural Engineering*, 37(4), 210–218.
33. Kimball, B. A. (1983). Carbon dioxide and agricultural yield: An assemblage and analysis of 430 prior observations. *Agronomy Journal*, 75(5), 779–788.
34. Kumar, A., Sharma, P. and Verma, S. (2021). Sustainable practices in floriculture: Challenges and advancements. *International Journal of Agricultural Sciences*, 17(2), 102–118.
35. Kumar, R., Sharma, A. and Verma, S. (2019). Greenhouse technology for sustainable horticulture. *Indian Journal of Agricultural Sciences*, 89(4), 567–575.
36. Kumar, R., Sharma, S. and Yadav, S. (2021). Integrated pest management in protected carnation cultivation: A review. *Pest Management Science*, 77(9), 3849–3856.
37. Liu, Y., Wang, H. and Chen, X. (2022). Light spectral management for greenhouse cultivation of ornamentals. *MDPI Plants*, 12(8), 1667.
38. Mahmud, M. S., Abidin, Z. Z. and Emmanuel, A. (2021). Robotics and automation in agriculture: A review. *Journal of Agricultural Automation*, 15(2), 56–68.
39. Maitra, S., Chatterjee, S. and Roy, S. (2020). Performance of Gerbera cultivars under protected cultivation in polyhouses. *Indian Journal of Horticulture*, 77(1), 70–77.
40. Maraveas, C. (2019). Environmental sustainability of greenhouse covering materials. *Sustainability*, 11(21), 6129.
41. Maraveas, C. (2022). Incorporating artificial intelligence technology in smart greenhouses: Current state of the art. *Applied Sciences*, 13(1), 14.
42. Martínez, L., Gomez, R. and Fernandez, J. (2023). Advanced light control strategies for protected cultivation systems. *International Journal of Horticultural Research*, 9(2), 145–160.
43. Miller, S., Patel, R. and White, T. (2022). Substrate selection impacts on orchid growth. *Orchid Science Review*, 25(1), 33–42.
44. Mohammed, A. A., Arkwazee, H. A., Mahmood, A. K., Mustafa, H. A. and Halshoy, H. S. (2023). Influence of phytohormones on seed germination of *Solanum linnaeanum*. *Anales de Biologia*, 1–8.
45. Mortensen, L. M. (1987). Review: CO₂ enrichment in greenhouses—Crop responses. *Scientia Horticulturae*, 33(1-2), 1–25.
46. Nath, A., Singh, M. and Patel, R. (2020). Evaluation of potting media for greenhouse roses. *Horticultural Science Advances*, 14(1), 45–52.
47. Nguyen, T., Smithson, A. and Lee, D. (2022). Post-harvest handling of orchids: Best practices. *Floral Industry Journal*, 18(4), 300–310.
48. Pal, D. and Karmakar, P. (2017). Population dynamics and management of *Polyphagotarsonemus latus* in Gerbera under protected conditions. *Journal of Entomology and Zoology Studies*, 5(6), 123–128.
49. Patel, K. (2023). Understanding orchid substrate requirements. *Horticultural Science Advances*, 22(3), 145–152.
50. Patil, V. and Singh, R. (2018). Microclimate management in polyhouse cultivation. *Journal of Horticultural Sciences*, 13(2), 210–218.
51. Rai, R., Meena, R. K. and Choudhary, S. (2020). Soil management and fertigation in polyhouse-grown carnations. *Horticultural Technology*, 12(3), 15–23.
52. Rajendran, K., Murugesan, T. and Radhakrishnan, R. (2014). Biocontrol of Fusarium wilt in Gerbera under protected cultivation. *Journal of Biological Control*, 28(3), 127–132.
53. Reddy, P. (2016). *Protected Cultivation of Horticultural Crops*. Scientific Publishers, India.
54. Reddy, P. and Gupta, N. (2021). Environmental control strategies for greenhouse cultivation. *Advances in Agricultural Research*, 15(3), 321–334.
55. Rodriguez, L., Greenfield, S. and Thompson J. (2022). Preventing fungal diseases in protected cultivation systems. *Plant Pathology Journal*, 29(6), 455–462.
56. Sharma, M., Joshi, P. and Mehta, R. (2020). Optimizing climate conditions in protected cultivation. *International Journal of Horticulture*, 7(1), 98–110.

57. Sharma, M., Shilpa, Kaur, M., Sharma, A. K. and Sharma, P. (2023). Influence of different organic manures, biofertilizers and inorganic nutrients on performance of pea (*Pisum sativum* L.) in North Western Himalayas. *Journal of Plant Nutrition*, 46(4), 600–617.
58. Singh, A., Kumar, S. and Mehta, D. (2021). Optimizing light intensity in greenhouse floriculture. *Springer Environmental Science and Technology*, 10(4), 567–589.
59. Singh, B., Kumar, M. and Meena, R. S. (2019). Advances in greenhouse technology for higher productivity. In R. S. Meena (Ed.), *Principles and applications of climate smart agriculture in agroecosystems* (pp. 275–300). Springer.
60. Singh, M., Yadav, A. and Singh, R. P. (2020). Propagation, pest control and crop management techniques for carnation under polyhouse conditions. *Journal of Horticulture and Plant Research*, 29(4), 56–63.
61. Singh, R. and Patel, D. (2022). High-tech interventions in protected floriculture: A review. *Journal of Horticultural Science*, 30(4), 215–230.
62. Singh, R., Kumar V. and Sharma P. (2023). Integrated pest management in orchids: Current trends and practices. *Journal of Pest Management*, 15(2), 99–110.
63. Slathia, D., Singh, A. and Sharma, P. (2018). Economic potential of floriculture under protected conditions. *Journal of Agricultural Economics*, 22(1), 45–56.
64. Smith, A. B. (2021). Protected cultivation of orchids: An overview. *Orchid Cultivation Journal*, 10(1), 5–15.
65. Sundararajan, S., Babu, S. V. and Venkatesh, P. (2020). Best practices for carnation cultivation under protected conditions. *Journal of Agricultural Research*, 48(4), 15–24.
66. Teixeira da Silva, J. A. (2003). Chrysanthemum: Advances in tissue culture, cryopreservation, postharvest technology, genetics and transgenic biotechnology. *Biotechnology Advances*, 21(8), 715–766.
67. Thakur, M., Verma, A. and Singh, R. (2021). Disease management in polyhouse carnations: Integrated approaches for improved growth. *Plant Disease Management Reports*, 15(3), 51–60.
68. Van Berkel, A. (2005). CO₂ enrichment strategies for greenhouse crops. *Horticultural Reviews*, 31, 129–169.
69. Velado, C., Martinez, A. and Gomez, H. (2020). Fuzzy logic controls for modern hydroponics. *Journal of Agricultural Engineering*, 42(1), 77–85.
70. White, T. and Green, R. J. (2021). The role of substrates in orchid health: A comprehensive study. *Journal of Botanical Research*, 14(4), 189–198.