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Horticultural Practices for Cut Flower Production in India: A Comprehensive Review

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Abstract

The floriculture industry in India has witnessed tremendous growth during the last two decades with cut flower production emerging as a high value agricultural industry. This review compiles the present status of horticultural practices for commercial cut flower production in India, major crops, agro-climatic requirements, protected cultivation systems, soil and substrate management, irrigation and fertigation practices, integrated pest and disease management (IPM), and post-harvest handling. The main cut flowers grown are rose, gerbera, carnation, lily, chrysanthemum, gladiolus and the emerging lisianthus, mostly under protected cultivation structures like naturally ventilated polyhouses and climate controlled green houses. Protected cultivation yields 4 to 10 times higher than open field systems with benefit-cost ratios up to 1.58. Precision fertigation with water-soluble fertilisers, drip irrigation and

integrated pest management (IPM) using biological, cultural and chemical methods are important horticultural interventions. Though there have been significant advances, constraints remain. High capital costs, poor cold chain infrastructure, poor availability of quality planting material and variable farmer knowledge are critical bottlenecks. India's cut flower exports are growing well with roses accounting for over 90% of greenhouse production for overseas markets. Future priorities include adoption of hi-tech cultivation, development of climate-resilient varieties, strengthening of post-harvest infrastructure and targeted capacity building. This review offers an in-depth framework for the researchers, extension professionals and practitioners engaged in the development of commercial cut flower industry in India.

Keywords: Cut Flowers, Protected Cultivation, Polyhouse, Fertigation, Integrated Pest Management, Post-Harvest Management, Floriculture, India

1. Introduction

Floriculture is one of the fast growing segments of Indian horticulture. It has developed from subsistence level loose flower cultivation to highly commercialised cut flower production system for domestic and global markets. Factors such as the liberalisation of the economy, rising consumer incomes, the expansion of the wedding and hospitality industries, and increasing international demand for tropical and temperate cut flowers have all served as catalysts for the transformation (Malviya *et al.*, 2022; Misra & Ghosh, 2016) [8, 9]. The global market for cut flowers is worth billions of dollars every year and offers huge potential for India, with its diverse agro-climate, low-cost labour and growing infrastructure for flower exports.

India has more than 0.32 million hectares of floriculture area and cut flower production is increasing steadily in both area and productivity. The agro-climatic advantage of the country from tropical peninsular India to temperate hill states makes year-round production of an unusually wide spectrum of species possible from tropicals like anthurium and heliconia to temperate requiring lily, carnation and certain rose hybrids (Nath & Datta, 2022; Sindhu & Saha, 2010) [10, 16]. This range has been further extended by protected cultivation technologies, which have allowed producers to manipulate local microclimates and maintain production throughout the year, even in non-traditional geographies (Gawande & Singh, 2024) [4]. Production clusters have emerged state-wise – notably in Karnataka, Maharashtra, Haryana, West Bengal and Tamil Nadu – with each region specialising in crops best suited to local agro-climatic conditions and market proximity.

AICRPF (All India Coordinated Research Project on Floriculture) has been operating for more than 20 research centers and has made a significant contribution in the development of location specific cultivation packages, release of new varieties and validation of polyhouse technology (Saha *et al.*, 2014) [13]. Some of the project's contributions are standardised fertiliser

recommendations, data on variety performance, specifications for polyhouse design and integrated pest management protocols tailored to Indian conditions. Despite these investments in research, there is still a large gap between recommended practices and on-farm implementation, especially for marginal producers. Although enhanced commercial cut flower production technologies have been reported to be adopted in areas like Meerut, barriers to knowledge transfer and input access still exist (Singh *et al.*, 2010) ^[17].

At the policy level, the National Horticulture Mission (NHM), Micro Irrigation Fund and programs of the Agricultural and Processed Food Products Export Development Authority (APEDA) have played a major role in the expansion of floriculture by providing capital subsidies, export incentives and market infrastructure funds. It is crucial that these policy instruments are connected with research-driven extension to hasten the shift from traditional to modern commercial production at scale.

The present review compiles the existing knowledge on horticultural practices for cut flower production in India. Based on peer-reviewed research from 2010 to 2025, it includes crop selection, agro-climatic management, design of protected cultivation, soil and nutrient management, irrigation strategies, pest and disease control, post-harvest handling, market dynamics and future priorities. The review is aimed to be an evidence-based reference for researchers, policy makers, extension workers and commercial growers in the rapidly evolving floriculture industry of India.

2. Major Cut Flower Crops in India

The cut flower industry in India has a wide range of crops for both domestic and export markets, with different species dominating different production zones based on agro-climatic suitability, market demand and available technology.

Rose is the most dominant flower in protected cultivation and more than 90 % of cut flowers grown in greenhouses are meant for export (Thakur *et al.*, 2012). Significant rose clusters are in Karnataka (Bengaluru region), Maharashtra (Pune), Haryana and Punjab. Hybrid tea varieties such as First Red, Super Star and Taj Mahal are cultivated for their long stem length, flower size and extended vase life. Economic analyses in Karnataka reveal a benefit-cost ratio of 1.58 for protected rose cultivation as opposed to 1.21 in open field systems (Gaddi *et al.*, 2024) ^[3]. Valuations for resource-use efficiency have shown that protected systems have greater variable costs, but far superior net returns per unit area (M. *et al.*, 2024) ^[7].

Gerbera is one of the most profitable secondary crops under polyhouse conditions in peninsular India. Most of the commercial cultivation of gerbera is in Karnataka, Maharashtra and Tamilnadu. The crop is prized for its bright colour, high stem strength and strong domestic demand from florists and event decorators. The economics of polyhouse production in Madhya Pradesh show viable returns if the costs of fertigation, plant protection and market prices are optimally managed (Tiwari *et al.*, 2020) ^[22].

Commercially **Carnation** is grown in hill states particularly Himachal Pradesh and also in polyhouse conditions in northern plains. The cultivars Impala, William Sim and Madame Collette are grown as both standards and sprays. Agronomical studies have shown considerable inter-varietal differences in stem height, flower diameter and vase life and

thus a careful selection of variety for specific market targets is needed (Tah & Mamgain, 2013) ^[19]. Polyhouse carnation production in Himachal Pradesh is helping family livelihoods with plants giving up to 35 harvesting flushes under optimal management (Bijalwan *et al.* 2017) ^[2].

Lilium (hybrid of Asiatic and Oriental) is a high value niche and has grown rapidly in north India. The usual practice is to propagate bulbs from September to December. Commercial cultivars such as Nashville, Eyeliner, and Hyde Park were evaluated under polyhouse conditions in semi-arid Haryana. Nashville is recommended for its stem quality and number of flowers under these conditions (Kumar *et al.*, 2018) ^[6]. Critical yield determinants in lilium production include spacing, cold storage of bulbs, and canopy management (Samantaray *et al.*, 2024) ^[14].

Lisianthus (*Eustoma grandiflorum*) is an emerging cut flower with huge commercial potential and is one of the ten most traded cut flowers in the world. India is in early adoption phase, predominantly in controlled environment systems. Challenges of the crop include photoperiod sensitivity, rosetting under suboptimal temperatures and complex seed germination requiring sophisticated greenhouse management and are the focus of active research (Subash *et al.*, 2025) ^[18].

Other commercially important species include **gladiolus** (widely grown in Uttar Pradesh, West Bengal and Karnataka), **chrysanthemum** (manipulated through photoperiodic control for year-round production), **tuberose** (*Polianthes tuberosa*, extensively grown in Tamil Nadu, Karnataka and West Bengal) and **anthurium** (grown in Kerala and northeastern states) (Sindhu & Saha, 2010; Nath & Datta, 2022) ^[16, 10]. **Marigold**, although a largely loose flower, has gained importance in the local cut flower markets and is being researched for its production and marketing (Panda *et al.*, 2022) ^[12].

3. Agro-Climatic Suitability and Variety Selection

Profitable cut flower production is based on crop selection matching with regional agro-climatic parameters. India's diversity of zones – from hot semi-arid Deccan plateau to humid Northeast, to cool Himalayan foothills – creates differentiated opportunities and constraints for each species. Temperature is the most important environmental variable. 28/18°C day/night temperatures are best for growth and flowering of roses. Carnation is well adapted to 10-13°C during winter and up to 15°C in summer with light intensity of 21.5 klux (Tah & Mamgain, 2013) ^[19]. Lilium under polyhouse conditions in Haryana has to face peak summer temperature of 45°C which needs appropriate shading and cooling management (Kumar *et al.*, 2018) ^[6]. Lisianthus is very sensitive to temperature, and exposure to temperatures below 10°C or above 30°C during seedling development causes rosetting, a key bottleneck for productivity (Subash *et al.*, 2025) ^[18].

The light needs of species producing cut flowers are very different. In protected cultivation structures, light transmission to the plants for photosynthesis needs to be balanced with temperature control by shading. In the advanced systems photoperiodic lighting has been used for production of chrysanthemum in such manner that the plants can flower throughout the year under controlled extension or interruption of the day-length. Similarly, supplemental lighting in the photosynthetically active radiation range of 400–700 nm is beneficial for lilium and gerbera production

during low irradiance winter months in northern India. The naturally ventilated polyhouses should be constructed with ultraviolet-stabilized polyethylene film with adequate light transmission of 60–80% of outdoor photosynthetically active radiation and adequate temperature moderation (Sheeba *et al.*, 2023) ^[15].

Choice of varieties must combine market demand with agro-climatic adaptation. Location-specific variety like Oriental hybrid liliun varieties for high altitude zones and Asiatic hybrids for semi-arid plains have been recommended by AICRPF trials (Saha *et al.*, 2014) ^[13]. Tah and Mamgain (2013) ^[19] conducted varietal evaluation studies in carnation and confirmed that floral characters like internode length, petal number and calyx length vary significantly among cultivars and hence systematic performance trials are indispensable before large scale commercial planting. Genotypic evaluation of water absorption and transpiration loss at senescence is very important in chrysanthemum for the identification of varieties suited to extended vase life in the domestic market (Kaur *et al.*, 2018) ^[5].

The Northeastern region of India, due to its high humidity and moderate temperatures throughout the year, is rich in significant untapped genetic resources and agro-climatic suitability for temperature-demanding species like orchids, anthurium, and gladiolus (Nath & Datta, 2022) ^[10]. In this region, agro-climatic fitness is not the limiting factor for floriculture development, but infrastructure and connectivity. At the same time, there is a rise in the diversity of species cultivated commercially to suit changing market preferences. Breeders and researchers are also increasingly focusing on heat-tolerant and disease-resistant varieties for the difficult climatic conditions of peninsular India.

4. Protected Cultivation Practices

Commercial cut flower production in India is backed by protected cultivation which gives 4-10 times yield multiplications over open field systems with substantial quality consistency (Nyola & Sharma, 2017; Gaddi *et al.*, 2024) ^[11, 3].

Three types of protected structures were used namely, naturally ventilated polyhouses (NVPH) with UV stabilised polyethylene film, shade net houses and climate controlled greenhouses with cooling and heating system. NVPHs are the most common type of housing in India because of lower capital cost (around Rs. 500–800/sq.m.), ease of construction and reasonable moderation of temperature. Large export-oriented rose and gerbera farms in Karnataka and Maharashtra use climate-controlled greenhouses, which are significantly more expensive (₹2,000–₹5,000/m²) (Gawande & Singh, 2024) ^[4]. Shade net houses are mainly used for hardening of transplants and for crops requiring light reduction such as anthurium and some orchids.

The microclimate conditions inside protected structures depend on the structure orientation, ridge height, ventilation area, and cover material selection. The NVPHs with spine orientation north-south and sufficient ventilation through sidewalls and roof, holds temperatures within 25–35°C range during summer in peninsular India for rose cultivation. Shade nets of 30–50% shading in high radiation zones during peak summer for high value crops sensitive to photoinhibition are used (Thakur *et al.*, n.d.) ^[20]. Commercial growers with larger operations are increasingly turning to multi-span greenhouse designs. These designs

provide better utilisation of space, lower structural costs per unit, and facilitate mechanisation of internal operations.

The technology adoption surveys conducted with protected cut flower growers in Tamil Nadu show that drip irrigation is almost universally adopted, fertigation is adopted by 100% of polyhouse operators and IPM adoption is 60.83% (Sheeba *et al.*, 2023) ^[15]. Automated greenhouse features, like vent control with programmable controllers, humidity sensors, and misting systems, are still only in large export-oriented operations but are on the rise as costs come down and technical support increases.

Training and staking are important cultural operations in the culture of protected roses. By periodically bending the unproductive shoots, also called “arching,” new productive shoots are stimulated and the productivity of the canopy is maintained. Pinching in carnation, removal of apical bud to induce branching is standard for spray carnation production (Tah & Mamgain, 2013) ^[19]. Spacing optimisation depends on the species: rose at 30 × 40 cm, gerbera at 30 × 30 cm, carnation at 15 × 15cm or 30 × 30cm, depending on variety and training system (Saha *et al.*, 2014) ^[13]. Wire trellis support systems for rose and carnation provide stem straightness – a quality parameter for premium grades.

5. Soil and Substrate Management

In protected cultivation, soil physical and chemical properties degrade more rapidly than in open fields, because of continuous cropping, high intensity fertigation and limited natural replenishment processes. Proper management of soil and substrate is, therefore, a prerequisite for long-term productivity and disease prevention.

Good drainage capacity is standard practice in gerbera and carnation production in raised beds to prevent crown and root rot caused by *Phytophthora* and *Pythium* species. For gerbera, the recommended growing medium is a mixture of coarse sand, composted coir pith and soil in the ratio of 2:1:1 (v/v) having pH of 5.5–6.5 and electrical conductivity (EC) of less than 1.2 dS/m (Sindhu & Saha, 2010) ^[16]. The growing medium of liliun should be well-drained and pre-treated with pre-plant fumigation or biological agents to suppress soil-borne pathogens (Samantaray *et al.*, 2024) ^[14]. For rose, a deep (45-60 cm) planting bed is necessary for vigorous rootstocks such as *Rosa indica* and *R. canina* with a deep root system and good aeration.

Management of organic matter through incorporation of well decomposed farmyard manure (FYM), compost or vermicompost improves soil structure, moisture retention and microbial activity. Pre-planting application of 20-25 tonnes FYM per hectare along with bio-inoculants like *Trichoderma* spp. and mycorrhizal fungi for better root health and nutrient uptake is standard practice for rose cultivation (Saha *et al.*, 2014) ^[13]. Soil solarisation with transparent polythene mulch during hot summer months before planting effectively reduces the populations of soil-borne pathogens and weed seed banks in polyhouses in semi-arid and sub-humid zones.

Repeated applications of fertilisers in intensive polyhouse cultivation can lead to salt build-up that can adversely affect root function. Periodic soil testing for pH, EC and macro-nutrients is essential. If EC is above safe levels, leaching irrigation (applying more water than the crop needs to wash out accumulated salts) is required to bring the quality of the growing medium back to acceptable levels. Regular

application of organic amendments will partly buffer excessive salt build-up.

Soilless culture, like cocopeat-based growing systems and hydroponics, is increasingly being adopted by large-scale growers, especially for the production of lisianthus, gerbera and high-end roses. Cocopeat substrates have higher moisture holding capacity, low bulk density and buffering capacity for fluctuations of pH and EC. The need for uniform substrate quality, avoiding soil-borne diseases, and scalability of production necessitates the shift to soilless culture (Subash *et al.*, 2025) ^[18].

6. Irrigation and Fertilization

The modern protected cut flower production system in India involves the precise management of water and nutrients through the use of drip irrigation and fertigation, which has revolutionised water-use efficiency, yield and flower quality.

Drip irrigation systems apply water directly to the root zone, decreasing foliar wetting and reducing the occurrence of fungal diseases and water loss from evaporation and runoff. Water requirement of cut flower crops under polyhouse conditions is generally in the range of 3 to 6 mm/day depending upon type of crop, stage of growth and season. With government subsidy, and productivity benefits, adoption of drip irrigation has been almost complete among protected flower growers in southern India (Sheeba *et al.*, 2023) ^[15].

Fertigation, i.e., the application of water-soluble fertilisers through drip systems, allows for precise spatiotemporal nutrient management in accordance to crop demand curves. The standard fertigation regime for rose cultivation is nitrogen:phosphorus:potassium in the ratio of about 200:60:200 kg/ha/year in multiple splits depending on phenological stages, i.e. high nitrogen during vegetative growth and high potassium during flower bud development and harvesting (Saha *et al.*, 2014) ^[13]. Micronutrient supplementation including chelated iron, zinc, boron and manganese is applied through the fertigation system to prevent deficiency symptoms that decrease stem quality and vase life.

In Gerbera fertigation protocols, a higher potassium ratio is used to improve petal colour intensity and stem strength during flowering (Tiware *et al.*, 2020) ^[22]. In the case of lily, fertigation enriched with phosphorus at early bulb establishment and potassium-dominant nutrition at the time of stem elongation and budding resulted in the highest number of flowers and stem length (Samantaray *et al.*, 2024) ^[14]. Sindhu & Saha (2010) ^[16] reported that anthurium responds to NPK formulations 30:10:10 or 30:20:20 at 0.2% concentration along with biostimulants such as gibberellic acid (GA3), Azospirillum and vesicular-arbuscular mycorrhizal (VAM) fungi to improve the spathe size and the frequency of production.

Economic analyses show that optimised fertigation consistently reduces total fertiliser cost and increases per-stem returns through improved stem calibre and flower grade (Gaddi *et al.*, 2024) ^[3]. The surveys indicated that among commercial cut flower growers, the most common advanced practices are the use of water-soluble fertilisers and scheduled fertigation, due to their visible effect on the performance of the crops (Singh *et al.*, 2010) ^[17].

7. Integrated Pest and Disease Management

Commercial operations of protected cut flower cultivation in polyhouses are characterised by a warm humid microclimate and continuous monoculture which increase the pressure of pests and diseases. The adoption of IPM among protected cut flower growers in India has been reported as 60.83% with scope for improvement (Sheeba *et al.*, 2023) ^[15].

The key diseases on major cut flowers are powdery mildew (*Sphaerotheca pannosa*) in rose, downy mildew and Botrytis blight (*Botrytis cinerea*) in gerbera and carnation, Fusarium wilt in carnation and gladiolus and damping-off in lisianthus seedlings by Pythium and Rhizoctonia species (Subash *et al.*, 2025; Sindhu & Saha, 2010) ^[18, 16]. Management strategies for disease include a combination of cultural practices (removal of plant debris, proper spacing for air circulation, irrigation scheduling to prevent extended periods of wetness on foliage) with targeted fungicide applications. Biological control agents such as *Trichoderma harzianum*, *T. viride* and *Pseudomonas fluorescens* have been found effective against soil-borne pathogens in rose and gerbera production systems (Saha *et al.*, 2014) ^[13].

Main insect pests are two-spotted spider mite (*Tetranychus urticae*) in rose and gerbera, western flower thrips (*Frankliniella occidentalis*) in carnation and lisianthus, aphids on many species and leaf miners on chrysanthemum. IPM strategies include yellow and blue sticky traps for pest monitoring and mass trapping, introduction of predatory mites (*Phytoseiulus persimilis*) for biological control of spider mites and use of selective, reduced-risk insecticides as a last resort. Neem-based formulations and insecticidal soaps are part of the standard components of low residue IPM programs, particularly in export-oriented farms that are required to comply with importing-country Maximum Residue Limits (MRLs) (Misra & Ghosh, 2016) ^[9].

Rosetting of lisianthus caused by phytoplasma infection transmitted by leafhopper vectors is a major emerging disease challenge that requires routine monitoring of vector populations and removal of infected plant material (Subash *et al.*, 2025) ^[18]. The phytosanitary certification of imported bulbs and planting material for lily is important to prevent the introduction of new pathogens, especially *Fusarium oxysporum* f. sp. *lilii* and tulip-breaking virus (Samantaray *et al.*, 2024) ^[14].

8. Post-Harvest Management and Quality Standards

One of the most critical and often underperforming stages in the cut flower value chain of India is post harvest handling. It is estimated that due to poor post-harvest management, 20-40 % of the commercially produced cut flowers are lost before reaching the end consumer, which leads to considerable economic waste for the producers and quality deterioration for the buyers (Tiwari & Bisen, 2024) ^[21].

Cut flowers right after harvest should be placed in water with acidifying agents (citric acid, pH 3.5–4.5) and antimicrobial compounds (quaternary ammonium salts or aluminium sulphate) to prevent stem blockage and bacterial growth in the vascular system (Halevy & Mayak, 1979). Timing and technique of harvesting have a large influence on postharvest longevity: roses harvested at the “pencil” bud stage in the early morning when stem turgor is at its highest show a better vase life than those harvested mid-day (Tiwari & Bisen, 2024) ^[21]. Pre-cooling to 2–4 °C within 2 h of

harvest greatly extends vase life by reducing respiration, ethylene production and water loss.

Cold storage for roses is maintained at 4–7 °C and for gerbera at 2–4 °C and is a common feature of export-compliant pack houses. However, such infrastructure is mostly found only in large farms (Saha *et al.*, 2014) ^[13]. Post-harvest conditioning is achieved by pulsing treatments with hydration solutions containing 8-hydroxyquinoline citrate, citric acid and sucrose. Chemical Vase Life Extenders: Silver Thiosulphate (STS) is used on ethylene sensitive crops such as carnation and lisianthus. STS effectively suppresses ethylene action and maintains petal texture and colour integrity. Frontier technologies with proven potential for extending the longevity of cut flowers include nano-silver formulations, plant-derived essential oil fumigants, and 1-methylcyclopropene (1-MCP) treatments (Tiwari & Bisen, 2024) ^[21].

Quality is graded as per Bureau of Indian Standards (BIS) norms and international grade specifications. Export-grade roses are classified by the length of the stem into grades of 40 cm, 50 cm, 60 cm, and 70 cm with the size of the flower bud, cleanliness of the foliage, and no damage from pests as additional criteria. For premium destination markets, the norm is export packaging in moisture absorbing corrugated fibreboard boxes with dry ice or gel packs in airfreight. Some of the most effective interventions for export competitiveness reported are pre-cooling, standardised grading and proper packaging (Malviya *et al.*, 2022) ^[8].

9. Export Potential and Market Dynamics

India's cut flower exports are growing steadily on the back of competitive production costs, increasing protected cultivation area and the growing acceptance of Indian roses and gerberas in global markets. In recent years, India's export earnings of cut flowers was around ₹680 crores with the Netherlands, United States, United Kingdom, Japan and UAE as the major destination markets (Misra & Ghosh, 2016; Balamurugan, 2019) ^[9, 1]. Logistically, the air cargo connectivity, more so from the international airports at Bengaluru and Mumbai, is critically important to support the perishable flower exports within the required time windows of transit.

Rose is the prominent commercial cut flower from large-scale protected cultivation units in Karnataka and Maharashtra and dominates export volumes. India competes in the international market mainly on price, increasingly supported by quality differentiation through Global G.A.P. and other certification schemes and consistent grading (Malviya *et al.*, 2022) ^[8]. Exports of gerberas are growing, especially to the nearby markets in South and Southeast Asia. The domestic cut flower market is also growing rapidly because of urbanisation, rising middle class incomes, growing organised retail and the expansion of the corporate gifting and hospitality sectors (Balamurugan, 2019) ^[1].

Economic analysis of cut flower farming in Rajasthan documented the production economics of open field systems and revealed viable economics even in water scarce regions when variety selection and market linkage are appropriate (Nyola & Sharma, 2017) ^[11]. Hi-tech protected cultivation has demonstrated the potential to transform the economic profile of marginal and large-scale farmers in several states such as Maharashtra. Access to subsidised polyhouse construction under the NHM and Pradhan Mantri Krishi

Sinchai Yojana has facilitated adoption (Gawande & Singh, 2024) ^[4].

The produce of producers outside the export supply chains is sold in the domestic flower markets, which consists of major auction centers and wholesale markets in Bengaluru, Mumbai, Delhi and Chennai. The lack of development of organised auction markets and price discovery mechanisms restricts the returns to growers in the domestic channel (Balamurugan, 2019) ^[1]. There are also major domestic opportunities in the growing institutional flower market segment serving hotels, hospitals, corporate offices and event management companies. This segment requires consistent quality and reliable supply volumes that often exceed the capacity of individual small producers. Floriculture producer organisations and farmer producer companies present an effective way to aggregate the supply, meet the standards and negotiate better prices in both domestic and export channels. The challenge is to develop organised cooperative structures, modern auction markets with transparent price discovery, and direct linkage of growers to international buyers through certification and branding programs as ways to improve sector competitiveness and equity.

10. Challenges and Future Directions

10.1 Production Constraints

The major constraint for adoption by small and marginal farmers (the majority of the floriculture workforce in India) is the high initial capital investment for polyhouse infrastructure. The construction costs for NVPHs (₹500–₹800/m²) and climate-controlled greenhouses (₹2,000–₹5,000/m²) remain prohibitive for smallholders without access to credit. Government subsidy programs under the NHM provide 50–65% capital support but procedural complexity and delayed disbursements reduce effective uptake (Gawande & Singh, 2024) ^[4].

Availability of quality planting material is a chronic constraint. At present India imports a major share of quality rose rootstocks, liliu bulbs and tissue cultured plants of gerbera which adds to cost and dependence on imports. Enhancing the domestic tissue culture capacity, bulb production programs, and vegetative multiplication systems will reduce import dependence and improve the availability of elite varieties (Subash *et al.*, 2025; Samantaray *et al.*, 2024) ^[18, 14]. The irregular supply of electricity in the production areas of rural locations affects the irrigation systems, cooling fans and cold storage operations and affects the continuity of production as well as post-harvest quality (Saha *et al.*, 2014) ^[13].

10.2 Post-Harvest and Market Challenges

Inadequate pre-cooling capacity at the farm level, insufficient refrigerated transport and limited cold storage in domestic markets, all symptomatic of inadequate cold chain infrastructure, lead to post-harvest losses of between 20 and 40 percent (Tiwari & Bisen, 2024) ^[21]. This infrastructure gap hits domestic market producers and small exporters the hardest. An immediate need in the value chain upgrade is investment in distributed pack houses, cold storage hubs and refrigerated vehicles, possibly through public-private partnerships (Misra & Ghosh, 2016) ^[9]. The volatility of market prices during festival seasons further challenges income stability of producers without storage capacity to

buffer supply-demand mismatches.

10.3 Knowledge and Technology Gaps

Knowledge gaps among farmers regarding improved package of practices constrain productivity and quality. While protected cultivation adoption has increased, proper implementation of fertigation management, IPM strategies, and post-harvest protocols remains inconsistent across the producer base. Extension systems must deliver crop-specific technical knowledge through multiple channels including on-farm demonstrations, training programs, and digital advisory platforms (Sheeba *et al.*, 2023) ^[15]. Research needs include development of climate-resilient varieties, optimization of fertigation protocols, refinement of IPM strategies, and innovation in post-harvest technologies (Saha *et al.*, 2014; Subash *et al.*, 2025) ^[13, 18].

10.4 Future Directions

Future development of India's cut flower industry requires integrated strategies across production, post-harvest, and marketing dimensions. Priority areas include continued development of hi-tech cultivation technologies such as climate-controlled greenhouses, automation systems, and precision agriculture tools that will enhance productivity and quality consistency (Gawande & Singh, 2024) ^[4]. Infrastructure investment in cold chains, pack houses, and organized auction markets is equally critical. Comprehensive capacity-building programs targeting farmers, extension workers, and value chain actors—delivered through demonstration farms, farmer producer organizations, and digital extension platforms—will accelerate technology diffusion. Policy support through streamlined subsidy access, favorable credit schemes, and export promotion investments will strengthen the enabling environment for sector growth.

11. Conclusion

India's cut flower industry has witnessed a major transformation from traditional loose flower cultivation to technically advanced commercially orientated production systems catering to premium domestic and international export markets. This transformation has been largely driven by protected cultivation technologies, particularly naturally ventilated polyhouses, which have led to yield increases of 4–10 times, year-round production and substantial quality improvements. The major cut flower crops, rose, gerbera, carnation, lily, chrysanthemum, gladiolus and the emerging lisianthus, all require a carefully calibrated horticultural package including structure design, variety selection, soil and substrate management, precision fertigation and integrated pest and disease management.

The economic evidences suggest that the protected cultivation is better in terms of net returns and benefit-cost ratios. However, high capital costs, import dependency on planting materials, electricity constraints, inadequate post-harvest infrastructure are major hindrances, especially to small and marginal producers. The gap between research-proven practices and their widespread implementation on farms needs to be bridged through strengthened extension systems, better access to credit and subsidies and development of organised market infrastructure.

India's favourable agro-climatic diversity, cost-competitive production advantages and increasing technical capacity provide a good base for continued growth of the floriculture

sector. Success in the future will require integrated investments in climate-resilient variety development, hi-tech cultivation, cold chain infrastructure and improved market access mechanisms. With appropriate policy support and sustained research and extension involvement, India's cut flower sector can achieve inclusive and sustainable development – providing profitable livelihoods for farming communities across various agro-climatic regions and increasing its share in the global floriculture market.

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