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RECENT BIOTECHNOLOGICAL INTERVENTIONS IN FLORICULTURE AND ORNAMENTAL CROPS: A REVIEW

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ABSTRACT

Over the last decade, floriculture and ornamental crop production have seen tremendous growth globally because of increasing scientific knowledge and technological interventions. Advances in tissue culture techniques, molecular breeding, and genome editing have allowed faster improvements in ornamental crops for quality, uniformity and availability of planting material, flower colour, form, disease resistance, shelf life or vase life etc. Greenhouses, polyhouses and shade-net structures have allowed floriculture growers to produce flowers throughout the year and have helped in scheduling flowering during specific seasons. Real-time monitoring of crop microclimate, irrigation water and nutrients is now possible with the Internet of Things (IoT) and artificial intelligence based prediction tools, enabling farmers to manage their crops precisely. Adoption of precision nutrient management and fertigation technologies along with soil less production systems have led to better use efficiency of nutrients and water, while reducing the overall cost of cultivation and pollution potential. Integrated approaches to improve postharvest handling, processing, and technologies have led to better harvesting techniques, reduced postharvest losses, better cold chain management, packaging and vase-life extension techniques using preservatives. The comprehensive coverage provided in this review of recent literature (2019-2025) will give researchers, extension workers and growers, an insight into the practical applications of recent advances and will provide tabular comparisons of important studies carried out under floriculture and ornamental plant production. Further, the review highlights the gaps in current research and suggests future areas of study to develop sustainable, climate smart and profitable floriculture systems.

Keywords: floriculture, ornamental crops, protected cultivation, biotechnology, postharvest, precision agriculture.

Introduction

Floriculture (cultivation of cut flowers, potted ornamentals, and bedding plants) has become a high-value horticultural subsector worldwide (Anumala and Kumar, 2021). The demand for decorative plants for

local markets, exports, and urban greening is on the rise both nationally and internationally. Value-adding techniques, mechanization and protected cultivation have all seen a steady increase in adoption. For instance, in recent years, India has reported growth in

both the acreage and production of cut and loose flowers (Kumar *et al.*, 2024).

Global trends show that the floriculture sector is steadily recovering and growing due to growing urbanization, the need for landscaping, and growing consumer demand for decorative plants (Zhang *et al.*, 2024). Increased demand for decorative crops for both local and export markets, especially in developing nations, is also evident in national-level estimates (Penna and Jain 2023). The yield, quality, and year-round accessibility of floricultural output have been greatly enhanced by the use of protected growing systems, mechanization, and value-addition techniques (Wani *et al.*, 2023). Recent statistics in India show a steady rise in the area and output of cut and loose flowers, which is indicative of floriculture's commercialization and technological acceptance (ICAR, 2024).

Despite these advancements, the industry still has to deal with issues such limited vase life, significant postharvest losses, poor cold chain infrastructure, a lack of workers, and rising climate variability (Girdhar *et al.*, 2025). Breeding and biotechnology advancements, protected culture, digital and precision farming technologies, better nutrient and growth regulation, and sophisticated postharvest management techniques are all helping to overcome these limitations (Partap, 2023). In order to emphasize technological advancement and sustainability-focused solutions for resilient floriculture systems, this study

synthesizes recent achievements across different fields (Wu *et al.*, 2025).

Technology and management advancements are addressing the sector's difficulties, which include limited vase life, high postharvest losses, a fragmented cold chain, labor constraints, and climatic variability. Modern methods in the areas of protected culture, digital/precision farming, nutrition and growth regulation, postharvest technologies, breeding/biotech, and sustainability are presented in this review (Wu *et al.*, 2025).

Advances in Breeding and Biotechnology

Conventional and Molecular Breeding

Because breeding directly modifies the genetic makeup of the plant to express desired phenotypes that satisfy market and production needs, it continues to be essential for improving significant ornamental traits in floriculture crops, such as novel flower colors, extended vase life, enhanced disease resistance, and compact growth habit (Rayalu & Anuradha, 2024). By enabling early and accurate selection of plants with desired traits, marker-assisted selection (MAS), a molecular breeding technique that uses DNA markers like SNPs and SSRs linked to target genes, is increasingly used to speed up the development of improved cultivars and lessen reliance on slow and inconsistent visual screening (Qurashi *et al.*, 2024; Patel *et al.*, 2025).

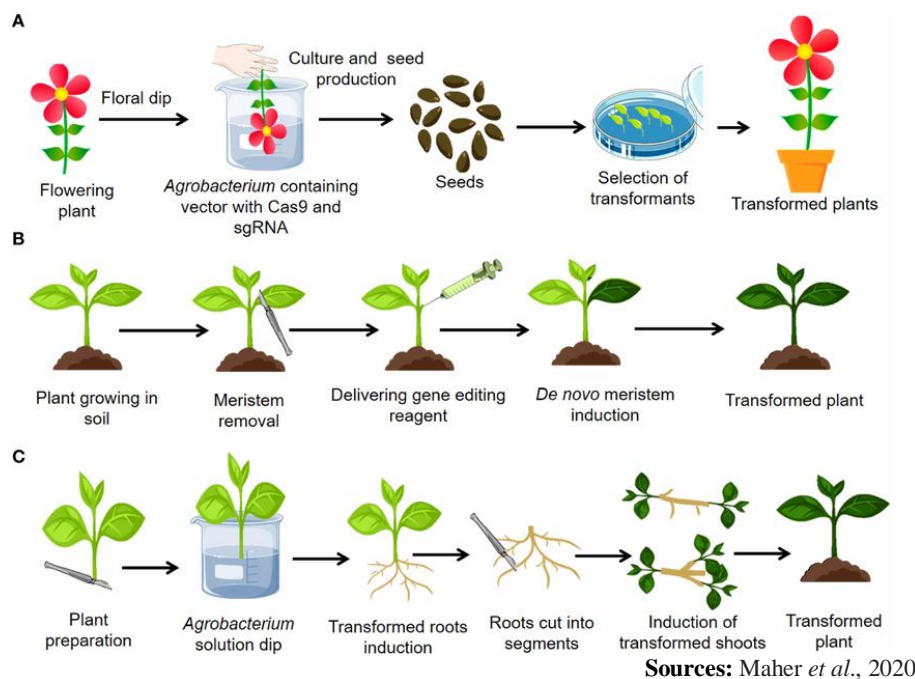


Fig. 1: Comparative Approaches in Plant Genome Editing: Floral Dip, Meristem-Based Editing, and *Agrobacterium*-Mediated Regeneration Using CRISPR/Cas9

MAS improves the tracking of quantitative trait loci (QTL) associated with complex features like as flower duration and disease resistance, hence enhancing selection efficiency over conventional breeding alone (Singh *et al.*, 2025; Patel *et al.*, 2023). Recent reviews have highlighted the use of molecular markers and next-generation sequencing technologies in conjunction with conventional breeding as a way to reduce breeding cycles by enabling breeders to select elite progeny before phenotypic traits fully manifest (Verma *et al.*, 2024). In addition to accelerating cultivar development, this combination of conventional crossing techniques with genomic technologies increases the genetic variety accessible for breeding programs, which is crucial for attaining long-lasting gains in ornamental crop performance (Singh *et al.*, 2025).

Because these features directly affect marketability and production efficiency, breeding is still essential for increasing ornamental qualities including new flower colors, longer vase life, improved disease resistance, and compact growth habit (Priyadharsini *et al.*, 2025).

Breeders may now find candidate genes and create genomic selection models for polygenic ornamental features more easily thanks to the combination of next-generation sequencing (NGS) with high-density markers (Aziz and Masmoudi 2025).

Tissue Culture & Micropropagation

For lilies, orchids, and chrysanthemums, mass propagation via tissue culture allows for the quick multiplication of elite cultivars free of diseases (Mehub *et al.*, 2022). Micropropagation also promotes the generation of homogeneous planting material for protected agriculture systems (Niranjan *et al.*, 2024)

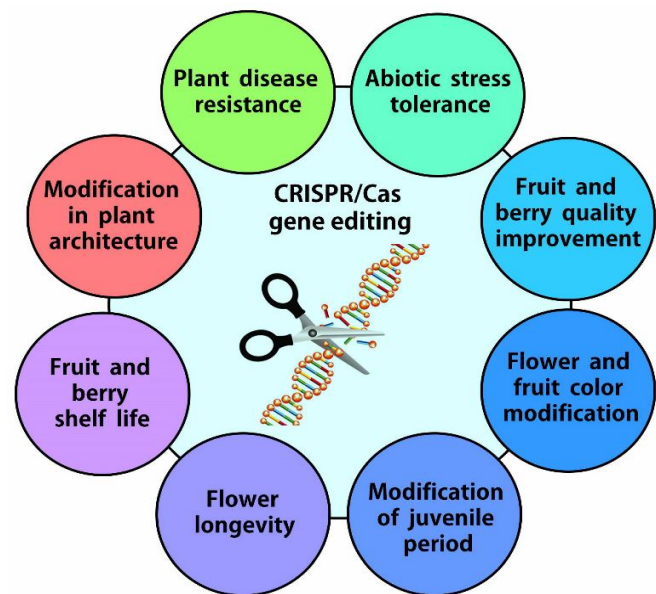
In order to provide disease-free and true-to-type planting material for commercially significant flower crops including lilies, orchids, and chrysanthemum, tissue culture techniques are commonly used (Ghosh, A. 2021). In ornamental production systems, the removal of systemic infections by meristem culture and indexing greatly enhances crop performance and plant health (Pandey *et al.*, 2025).

Genetic Engineering & Genome Editing

For specific modifications (flower color, senescence processes, disease resistance), ornamental species are starting to use CRISPR/Cas9 and other gene-editing techniques (Raheena *et al.*, 2025). Reviews highlight both commercial and regulatory obstacles as well as opportunities. Candidate genes for

editing can be found by integrating omics (transcriptomics, metabolomics) (Adebayo *et al.*, 2020). Key regulatory genes governing pigment biosynthesis and ethylene-mediated senescence processes in ornamentals have been successfully edited in recent studies, leading to enhanced aesthetic quality and longer vase life (Tang *et al.*, 2023).

Reviews highlight that despite their potential, popular acceptance, regulatory ambiguity, and high commercialization costs continue to be significant barriers to the widespread use of gene-edited ornamental crops (Din *et al.*, 2025).



Sources: Jaganathan *et al.*, 2018

Fig. 2: CRISPR/Cas-Mediated Trait Enhancement in Fruits, Flowers, and Ornamental Crops

Protected Cultivation & Controlled Environment Horticulture

Greenhouses, Polyhouses and Shade Nets

Year-round production, off-season availability, enhanced quality, and increased resource-use efficiency are all benefits of protected cultivation (Jalwania *et al.*, 2025). With significant acreage in Europe and other places, China leads the world in the expansion of the area under protected agriculture (Wu *et al.*, 2017). Although adoption is growing in India, knowledge gaps and financial costs continue to be obstacles (Uwimana *et al.*, 2024).

Protected cultivation for floricultural crops is becoming more and more popular in India, but its broader spread is still hampered by high initial investment costs, a lack of technical expertise, and limited availability to experienced labor (Janbandhu *et al.*, 2024).

Soilless Systems & Hydroponics

High-value potted plants and specialty cut flowers cultivated in controlled surroundings benefit greatly from soilless culture (hydroponics, substrate-based systems), which enables precise nutrient control, fewer pests, and increased yield per area (Lakhiar *et al.*, 2025).

Climate Control & Energy Use

Modern environmental control technologies, including as automatic ventilation, fogging, heat exchangers, and LED lighting, enhance temperature, humidity, and light quality all of which are essential for the timing and quality of blooming. Low-cost sensors and energy efficiency are current research areas (Vikanksha *et al.*, 2023).

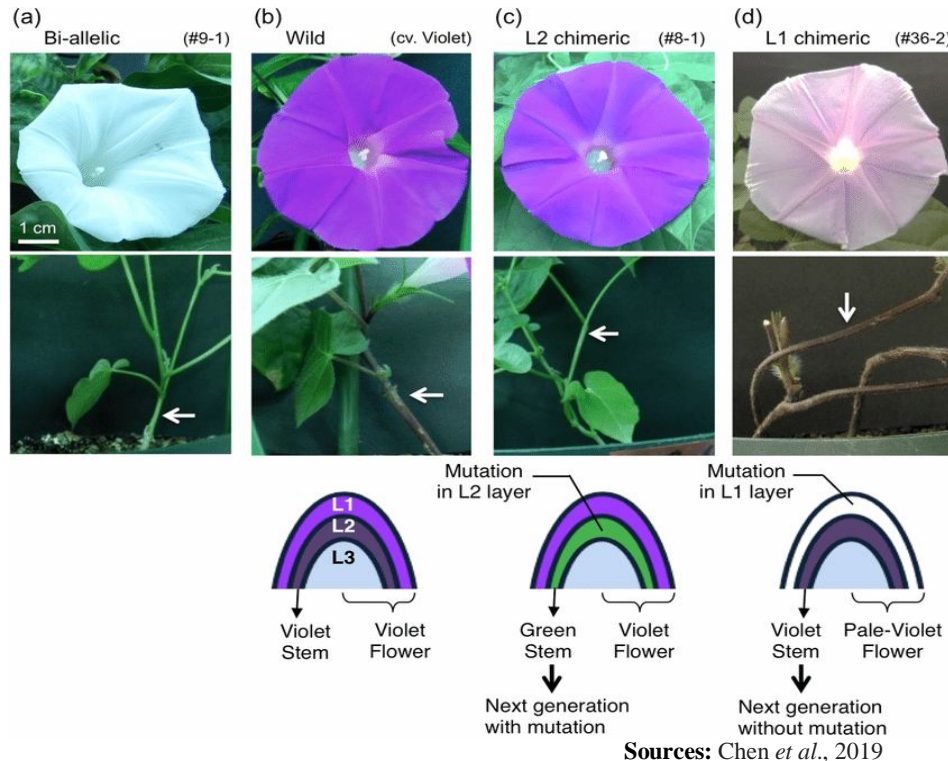
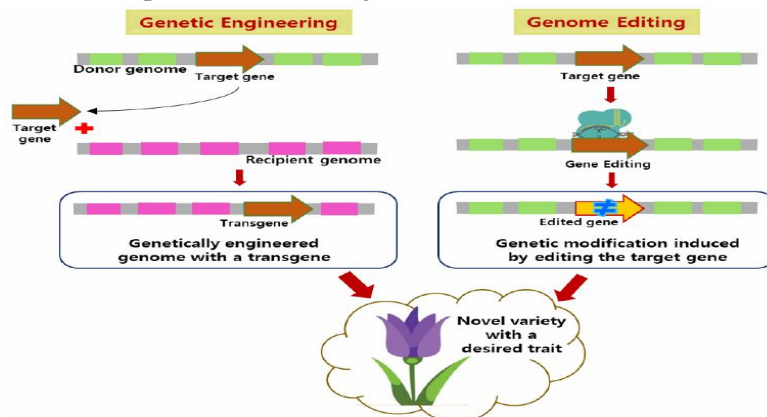


Fig. 3: CRISPR/Cas9-Induced Layer-Specific Mutations and Chimerism Affecting Flower Color in *Ipomoea nil* (Morning Glory)
Sources: Chen *et al.*, 2019

**4. Precision Agriculture, Digitalization & Automation
Sensors, IoT and Decision Support**

Real-time monitoring of the microclimate, soil moisture, and nutrient status is made possible by the use of inexpensive sensors and IoT platforms, allowing

for data-driven management and decreased input waste (Mansoor *et al.*, 2025). In greenhouses, decision support systems aid in the scheduling of fertigation, watering, and climate management (Bhardwaj *et al.*, 2024).



Sources: Chen *et al.*, 2019

Fig. 4 : Comparison of Genetic Engineering and Genome Editing Approaches for Crop Improvement

Machine Vision, Robotics and AI

Although robotic harvesters and automated packing systems are being developed, the use of machine vision systems for flower detection, sorting, and quality assessment is still limited in floriculture compared to field crops because flowers are delicate (Mantilla *et al.*, 2025). Recent developments in object detection algorithms, such as YOLO versions, have

demonstrated potential for focused operations and flower/inflorescence detection (Khanal *et al.*, 2023).

Targeted operations like selective harvesting and yield estimation are made possible by recent developments in deep learning-based object detection algorithms, especially YOLO variants, which have shown high accuracy and efficiency in identifying flowers and inflorescences under challenging field and greenhouse conditions (Li *et al.*, 2023).

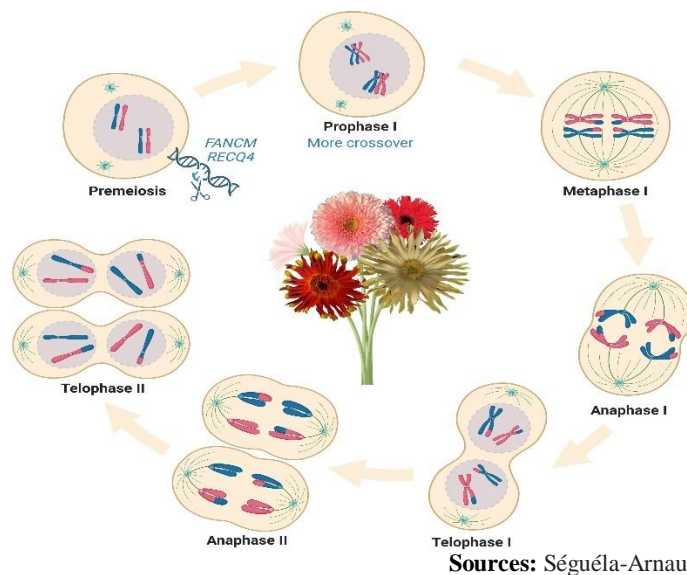


Fig. 5 : Regulation of Meiotic Recombination and Crossover Formation in Flowering Plants.

Nutrient Management, Bio stimulants and Growth Regulators

Precision Fertigation and Micronutrients

In protected and soilless settings, precision fertigation enhances bloom quality and nutrient use efficiency. For flower production and vase life, balanced NPK regimens and micronutrients like Zn, Fe, and B are essential. Foliar micronutrient sprays are beneficial for ornamentals, according to studies (Ali *et al.*, 2024).

In addition to balanced NPK fertilization, micronutrients like zinc (Zn), iron (Fe), and boron (B) are essential for floral bud initiation, pigment synthesis, pollen viability, and vase life of ornamental crops (Kisvarga *et al.*, 2022).

Bio stimulants, Nanomaterials and Biofertilizers

To improve stress tolerance, flowering, and postharvest quality, biostimulants (humic acids, seaweed extracts), biofertilizers, and innovative nano-formulations are being tested (Matthews *et al.*, 2022). Although environmental and regulatory issues still need to be taken into account, recent research indicate

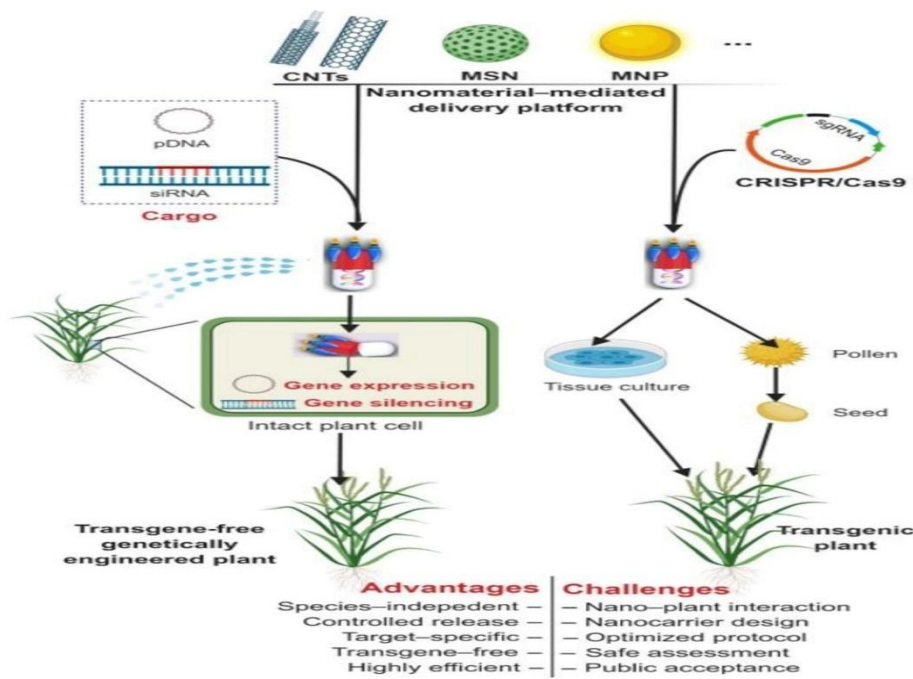
that therapies based on nanoparticles may increase vase life and disease resistance (Namratha *et al.*, 2024).

Although concerns about environmental safety, dose optimization, and regulatory approval remain crucial for widespread adoption, recent studies show that nanoparticle-based treatments, such as nano-silver, nano-zinc, and nano-silica, can significantly improve vase life, reduce microbial blockage, and enhance resistance against postharvest pathogens in ornamental flowers (Rouphael and Colla, 2020).

Plant Growth Regulators (PGRs)

To regulate blooming time, stem elongation, and postharvest senescence, PGRs (such as cytokinins, gibberellins, and ethylene inhibitors as silver thiosulfate substitutes) are widely utilized (Kumar *et al.*, 2021). Optimizing timing and dosages enhances flower uniformity and lessens unwanted effects (Das *et al.*, 2025).

According to recent research, optimizing PGR type, dosage, and stage-specific treatment greatly lowers physiological disorders, minimizes unfavorable side effects, and enhances floral uniformity, market quality, and vase life in ornamental crops (Serek and Reid 2024).



Sources: Han *et al.*, 2019

Fig. 6 : Nanomaterial-Mediated Delivery Platforms for CRISPR/Cas9 and Gene Silencing in Plants

Stress Physiology and Climate Resilience

Flowering phenology and pest/disease dynamics are impacted by climate change (temperature extremes, unpredictable rainfall). Mulches, shade, evaporative cooling, and the choice of resistant cultivars are some of the management options made possible by research on stress physiology, including heat, drought, and salinity (Fanourakis *et al.*, 2025). Resilient floriculture prioritizes integrating insights into stress physiology with protected cultivation and biostimulants (Sharma *et al.*, 2025).

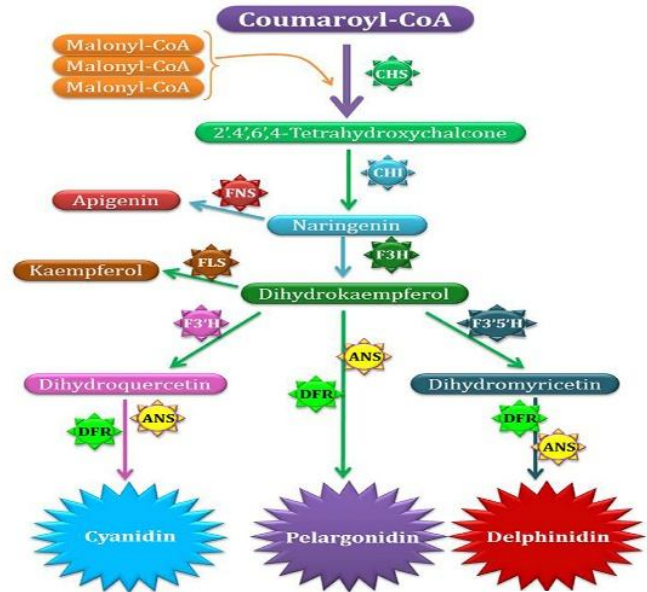
It is becoming more widely acknowledged that a fundamental tactic for creating climate-resilient and sustainable floriculture production systems is the integration of stress physiology-based techniques with protected cultivation technology and the use of biostimulants (Tirkey *et al.*, 2023).

Postharvest Management and Value Addition

Vase Life Extension Strategies

Harvest time, hydration, preservatives, and the cold chain are all crucial aspects of postharvest treatment. By tackling microbial obstructions, oxidative stress, and carbohydrate depletion, preservation strategies (sucrose, citric acid, antibacterial agents, and new materials) prolong vase life. Vase life and quality can be quickly predicted according to recent research on Vis/NIR spectroscopy (Wu *et al.*, 2025). By preventing microbial blockage in xylem vessels, preserving carbohydrate balance, and lowering oxidative stress during postharvest storage,

preservation methods employing sucrose, citric acid, antimicrobial agents, and new environmentally friendly compounds help prolong vase life (Wu *et al.*, 2025; Costa *et al.*, 2023).



Sources: Saito, K. 2025

Fig. 7 : Flavonoid and Anthocyanin Biosynthetic Pathway Leading to Cyanidin, Pelargonidin, and Delphinidin Production in Plants.

According to recent research, visible and near-infrared (Vis/NIR) spectroscopy provides a quick, non-destructive method for forecasting the freshness, vase life, and postharvest quality of cut flowers, improving sorting and postharvest decision-making (Wu *et al.*, 2025; Zhang *et al.*, 2024).



Sources: Chen *et al.*, 2019

Fig. 8 : Emerging Technologies in Modern Floriculture: From CRISPR Gene Editing to Smart and Urban Farming Systems

Packaging, Cold Chain and Logistics

Losses are a significant barrier in developing markets, but they can be reduced with improved packing (insulated shipping, controlled atmosphere), a dependable cold chain, and logistics. Growers' revenue streams are diversified by value addition (drying, essential oils, and flower extracts) (Vivek *et al.*, 2019).

Postharvest losses of cut flowers, which continue to be a major obstacle in developing floriculture markets, are greatly reduced by improved packaging technologies like insulated transport systems, controlled-atmosphere packaging, and an effective cold chain and logistics network (Kuzichev and Kuzicheva 2016).

Urban, Vertical and Indoor Floriculture

In order to feed city markets, improve urban biodiversity, and create jobs, urban floriculture (rooftop, vertical farming, indoor plant production) takes advantage of underutilized urban locations. Hydroponics, containerized ornamentals that are adapted to lower light levels, and vertical racks with LED illumination are some of the methods. Reviews indicate scale-up prospects and limitations (Rabiya *et al.*, 2024).

Particularly in highly populated areas, urban floriculture which includes rooftop gardens, vertical

farming, and indoor plant production—uses unused urban spaces to supply local markets, improve urban biodiversity, and generate jobs (Ferrante and Ferrini 2023).

The potential and limitations of expanding urban floriculture are highlighted in recent evaluations, which also emphasize issues such high beginning costs, the need for technical expertise, and restrictions imposed by urban policies (Costa *et al.*, 2023).

Market, Policy and Sustainability Aspects

Production decisions are influenced by market demand, export regulations, and sustainability factors (lower pesticide residue, carbon footprint). Policies that encourage cold chain investment, training, and smallholder adoption of protected cultivation are essential, especially in nations with fragmented floriculture industries. Indian research highlights the necessity of infrastructure to lower postharvest losses, which have been reported to be between 25 and 30 percent (Vivek *et al.*, 2023).

At the national and international levels, floriculture production systems can be made resilient and profitable by combining market intelligence, sustainability standards, and supportive policies (Singh and Meena, 2024).

Table 1 : Key technological advances in floriculture: summary of function and benefit.

Technology / Approach	Main function	Practical benefit(s)	Selected recent refs
Protected cultivation (greenhouse/ polyhouse)	Environmental control	Year-round production; improved quality; higher yields	
Soilless culture (hydroponics)	Root environment control	Precise fertigation, reduced pests; higher density production	Adebayo <i>et al.</i> , 2020
Tissue culture/ micropropagation	Rapid multiplication	Pathogen-free, uniform planting material	Adebayo <i>et al.</i> , 2020
CRISPR and genomics	Trait modification/ selection	Faster trait development (colour, senescence, disease resistance)	Bhardwaj <i>et al.</i> , 2024
IoT & sensors	Real-time monitoring	Precision irrigation/ fertigation, reduced inputs	Bhardwaj <i>et al.</i> , 2024
Machine vision & robotics	Harvest/ sorting/quality control	Labor saving, consistent grading (emerging)	Khanal <i>et al.</i> , 2023
Postharvest preservatives & tech	Vase life extension	Reduced losses, improved exportability	Wu <i>et al.</i> , 2025

Table 2 : Representative recent studies on postharvest and vase life (2019–2025)

Study (first author, year)	Crop	Treatment(s) evaluated	Key result
Wu, Y. (2025)	Multiple cut flowers (review)	Preservation agents, carbohydrate + acid regimes	Summarized mechanisms; identified microbial control + carbohydrate supply as key.
Ham, JY. (2025)	Roses	Vis/NIR spectroscopy for rapid quality estimation	Vis/NIR predicted water content and vase life reliably (R^2 up to 0.77).
Thaku 2022	Strelitzia	Graphene oxide + silver nanoparticles	Improved postharvest life as biostimulant in experiments (lab scale). Thaku 2022
BHANWALA 2021	Tropical cut flowers	Cold chain and handling	Highlighted need for improved cold chain; selective preservatives recommended. BHANWALA 2021

Synthesis: What's working and knowledge gaps

Working / well-adopted approaches

- Soilless systems and protected cultivation provide high-value crops with consistent quality. Kumari and Rajiv, 2023.
- For many ornamentals, tissue culture is the norm for quick proliferation. Adebayo *et al.*, 2020
- Investments in the cold chain and postharvest preservative concoctions clearly increase vase life and marketability. Wu and associates, 2025

Persistent gaps and research needs

- Cost-effective adoption of automation and robotics for delicate flowers. Khanal *et al* 2023
- Environmental and safety evaluation of nanomaterials and novel biostimulants. Magnabosco *et al.*, 2023
- Integrated decision support systems tailored to smallholder producers in developing regions. Churi *et al.*, 2023

- Stronger cold chain and logistics in many producing countries (e.g., India) to reduce 20–30% postharvest losses. Kaur *et al.*, 2024

Conclusions and Future Prospects

Genetics, protected cultivation, precise nutrition and water management, and computerized decision tools are all part of the integrated, technologically advanced systems that floriculture is transitioning to. To turn production gains into commercial value, postharvest science and the cold chain are still essential. The following are important future directions:

- (1) responsible gene editing and nanotech deployment with environmental safety assessment;
- (2) cost-effective automation for small and medium-sized businesses;
- (3) scalable cold chain and logistics solutions;
- (4) customized extension to boost protected cultivation adoption in areas with high demand. Transforming technological advancements into fair growth throughout the floriculture value chain will

require ongoing interdisciplinary research and governmental assistance.

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