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Postharvest management and value-addition in ornamental crops: strategies for shelf-life extension and economic enhancement

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Abstract

Ornamental crops constitute a high-value component of horticulture but are highly perishable, resulting in substantial postharvest losses estimated at 30–40% under conventional supply chains. These losses arise from complex interactions among physiological, biochemical, and environmental factors, including respiration, ethylene sensitivity, water imbalance, and oxidative stress. This review critically synthesizes existing literature on postharvest physiology and management of ornamental crops, highlighting key determinants of senescence and evaluating current technologies for shelf-life extension. Comparative analysis of studies indicates that no single factor governs deterioration; rather, integrated effects of carbohydrate depletion, ethylene action, and xylem blockage collectively influence vase-life. Postharvest interventions such as pre-cooling, pulsing with preservative solutions, and maintenance of cold chain systems have demonstrated significant effectiveness, although their adoption remains limited by infrastructural constraints. Value-addition emerges as a complementary strategy to reduce losses and enhance profitability through conversion of flowers into dried products, essential oils, pigments, and nutraceuticals. However, lack of standardization, technical knowledge, and market linkages restricts large-scale implementation. Emerging approaches, including nanotechnology-based coatings, eco-friendly preservatives, and smart packaging systems, offer promising avenues but require further validation for commercial application. The review identifies critical research gaps in integrated postharvest management and sustainable value-addition, emphasizing the need for cost-effective, eco-friendly technologies and improved supply chain infrastructure to enhance the competitiveness of the floriculture sector.

Key words: Cold chain, Ethylene, Floriculture, Ornamental crops, Postharvest management, Reactive oxygen species, Senescence, Vase-life, Value-addition

Ornamental crops constitute a high-value segment of horticulture, with increasing global demand driven by urbanization, lifestyle changes, and expanding floriculture markets. The global cut flower market was valued at approximately USD 10.7 billion in 2024 and is projected to exceed USD 14 billion by 2030 (Faust and Dole, 2021), underscoring the economic significance of effective postharvest management. However, their commercial potential is severely constrained by high postharvest losses primarily due to physiological deterioration and inadequate supply chain management (Kader, 2002; Reid and Jiang, 2012). Earlier studies emphasized infrastructural limitations such as lack of cold chain and improper handling (Nowak and Rudnicki, 1991), more recent research highlights the dominant role of intrinsic physiological processes, particularly respiration, ethylene sensitivity, and water imbalance, in determining postharvest longevity.

Postharvest deterioration is now understood as a complex, multi-factorial process rather than a single-cause phenomenon. Classical work by Halevy and Mayak (1979) established the hormonal regulation of senescence, whereas subsequent studies by Reid and Jiang (2012) emphasized the interaction between ethylene and carbohydrate depletion. In contrast, van Doorn (1997) proposed that hydraulic failure due to xylem blockage is often the primary limiting factor in vase life. These differing perspectives indicate that postharvest longevity is governed by the interplay of metabolic, hormonal, and physical factors.

In parallel, value-addition has gained attention as a strategy to offset postharvest losses and improve profitability. While earlier approaches focused primarily on fresh flower marketing, recent studies demonstrate that processing into dried products, essential oils, and natural dyes can increase returns significantly and stabilize market fluctuations (Singh *et al.,* 2018; Shah *et al.,* 2022). However, despite its potential, adoption of value- addition technologies remained limited due to lack of standardization and infrastructure.

The review is based on a systematic survey of literature published between 1979 and 2026, drawn from peer-reviewed journals, book chapters, and conference proceedings. It differs from earlier reviews by integrating both the physiological basis of postharvest deterioration and practical value-addition strategies within a unified framework, with particular emphasis on emerging technologies and research gaps specific to the Indian floriculture sector. We have critically evaluated current knowledge on postharvest physiology, handling strategies, and value-addition in ornamental crops, with

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emphasis on identifying key determinants of senescence, comparing existing technologies, highlighting research gaps for sustainable floriculture development.

Postharvest Physiology and Constraints

Respiration and senescence

Respiration is widely recognized as a primary determinant of postharvest longevity due to its role in depleting carbohydrate reserves required for cellular maintenance (Halevy and Mayak, 1981; Reid and Jiang, 2012). Reid and Jiang (2012) suggested that the rapid carbohydrate depletion accelerates senescence and reduces vase life. However, this view has been challenged by van Doorn, who argued that carbohydrate status alone cannot explain wilting, emphasizing instead the role of hydraulic failure (van Doorn, 1997). This indicates that respiration interacts with other physiological processes rather than acting independently. Beyond substrate depletion, declining ATP availability compromises membrane ATPase activity, leading to electrolyte leakage and accelerated tissue senescence — a mechanism particularly relevant in petals with high metabolic rates (Ma *et al.,* 2018). Elevated midday temperatures increase respiratory activity; consuming carbohydrate reserves more rapidly and generating metabolic heat that exacerbates oxidative stress. Harvesting in cooler periods, such as early morning or late afternoon, reduces respiratory rates, conserves energy, and slows senescence (Ahmad *et al.*, 2014).

Role of ethylene

Ethylene is a key regulator of flower senescence, particularly in climacteric species such as carnation and rose (Halevy and Mayak, 1981; Reid, 1989). Early work by Halevy and Mayak demonstrated that ethylene accelerates petal wilting, abscission, and membrane degradation. Subsequent studies confirmed that even trace concentrations (as low as 0.1 $\mu L\ L^{-1}$) significantly reduce vase life (Pun *et al.,* 2003 and Baron *et al.,* 2021). However, species-specific variation in ethylene sensitivity suggests alternative regulatory pathways. Ethylene-insensitive flowers such as gladiolus and lily exhibit senescence more closely associated with carbohydrate depletion and oxidative stress (van Doorn, 2000). New regulators like salicylic acid, polyamines, and nitric oxide extend flower life by reducing ethylene production and enhancing cell functions (Tatte *et al.,* 2016). Use of ethylene scavengers, like 1-MCP, blocks ethylene binding sites, prolonging flower freshness (Hoppen 2020) while specifically, fumigation with EthylBloc improved rose display life, whereas Smart Fresh reduced ethylene production in cut carnations and roses (Nergi and Ahmadi, 2014).

Water relations and xylem blockage

Water balance is increasingly recognized as a critical determinant of postharvest longevity. Microbial proliferation at the cut stem ends leads to xylem blockage, restricting water uptake and causing wilting (van Doorn, 1997; van Doorn and Cruz, 2000). Experimental studies have shown that antimicrobial preservatives significantly improve solution uptake and extend vase life (Jain *et al.,* 2007; Jain *et al.,* 2014). Re-cutting stems at an angle under water removes air emboli and surface microbes, immediately restoring hydraulic conductance; this simple physical intervention, when combined with antimicrobial holding solutions, can increase water uptake by 40–60% compared to controls (van Doorn and Cruz, 2000). However, some researchers argue that vascular blockage alone cannot fully explain senescence, suggesting that it interacts with metabolic and hormonal processes (Jones and Hill, 1993). Thus, water relations represent a central but interdependent factor in postharvest deterioration.

Oxidative stress and biochemical changes

Oxidative stress has emerged as a key mechanism underlying senescence. Accumulation of reactive oxygen species (ROS) and decline in antioxidant enzymes such as SOD, CAT, and peroxidases lead to membrane lipid peroxidation and cellular damage (Tripathi and Dubey, 2004; Ma *et al.,* 2018). Importantly, ROS also upregulate ACC synthase activity, creating a positive feedback loop between oxidative stress and ethylene biosynthesis that further accelerates the rate of senescence (Ma *et al.,* 2018). Application of antioxidant compounds such as ascorbic acid has been shown to maintain enzyme activity and delay senescence in chrysanthemum (Jain and Janakiram 2016; Varun *et al.,* 2018a and 2018 b). However, the effectiveness of such treatments varies across species, indicating the need for crop-specific optimization. Varun *et al.,* (2019) reported that spraying of 100 ppm ascorbic acid on cut chrysanthemum cv. Pusa Centenary significantly improved vase-life by maintaining chlorophyll content, enhancing membrane stability, and regulating antioxidant enzymes (SOD, CAT, POX).

It reduced oxidative stress (H_2O_2 accumulation) and effectively delayed leaf yellowing and p*etal* senescence compared to untreated flowers. Application of boric acid (4%) and salicylic acid (50 ppm) in tuberose, particularly when combined with muslin cloth packaging, enhanced antioxidant enzyme activities (CAT, SOD, and guaiacol peroxidase) under both ambient and cold storage. Enzyme activity generally increased during storage and declined at the end of vase-life, indicating their role in delaying senescence and maintaining flower quality

(Singh *et al.,* 2023). Enzyme-mediated degradation of proteins and cell wall components further contributes to tissue softening and petal abscission (Kenichi *et al.,* 2016).

Synthesis and research gaps

The postharvest deterioration is governed by the interaction of respiration, ethylene signaling, water imbalance, and oxidative stress (van Doorn and Curz, 2000; Reid and Jiang, 2012). However, most research has focused on individual factors rather than integrated mechanisms. There is a need for systems-level approaches and greater emphasis on eco-friendly preservative technologies.

Harvesting and handling

Harvest maturity significantly influences postharvest performance, with optimal stage varying across species and market requirements (Nowak and Rudnicki, 1991; Kader, 2002). Long-distance transport necessitates earlier harvesting at the tight bud stage (Faust and Dole 2021). Early harvesting improves transportability but may limit flower opening, whereas late harvesting enhances aesthetics but reduces vase-life. Loose flowers like jasmine, crossandra and tuberose are harvested at bud stage which have several advantages like ease of treatment with preservatives, packaging, transport, withstanding rough handling, moreover, the flower buds are insensitive to ethylene. Flowers harvested at more advanced stage of development have shorter vase life than younger flowers. Coordinated harvesting aligned with diurnal physiology—especially during cooler periods such as early morning—optimizes water status, conserves carbohydrate reserves, reduces field heat and evaporative water loss, lowers respiration stress, and slows senescence, thereby sustaining cut flower quality and extending vase life, whereas midday or afternoon harvesting increases water stress and accelerates senescence (Varu and Barad, 2007; Taylor *et al.,* 2008).

Pre-cooling is widely recognized as an effective method for reducing respiration and ethylene production (Kader, 2002, Jain *et al*, 2018). For instance, vacuum cooling of cut roses to 1–2°C within 30 minutes of harvest has been shown to reduce respiration rate by 50–60% and extend vase life by 3–4 days compared to ambient-cooled controls (Cevallos and Reid, 2001). However, its adoption is constrained by infrastructural limitations in many regions. Floral preservatives are essential for improving colour, flower size, and shelf life in loose flowers (Rudnicki *et al.* 1991). These preservatives typically contain sugars like sucrose, which acts as a food source, slows protein degradation and maintains turgidity (Rani and Singh 2014). Pulsing treatments with sucrose and antimicrobial agents such as 8-HQC, citric acid, and aluminium sulphate have consistently been shown to improve water uptake and vase life (Jain *et al.,* 2007; Jain *et al.,* 2017). Recent studies have explored eco-friendly alternatives such as salicylic acid and sulpho-salicylic acid, although their commercial applicability remains limited (Jain *et al.,* 2021).

Postharvest life of flowers can be controlled by growth regulators. Growth regulators modulate postharvest longevity through distinct hormonal pathways. Cytokinins (*e.g.,* thidiazuron) delay leaf and petal senescence by maintaining chlorophyll content and protein synthesis. Gibberellins (GA_3) at optimized concentrations promote floret opening and extend longevity, whereas abscisic acid (ABA) generally accelerates senescence; however, at very low concentrations (~1 ppm) in continuous holding solution, it delays wilting and extends the longevity of cut roses by inducing stomatal closure. Depending upon the concentrations, GA_3 in some cases promotes longevity of flowers, while it is also used in bud opening solution. The senescence and abscission of poinsettia flowers is delayed by auxin (Siddiqui, 2015). Nitric oxide donors such as sodium nitroprusside suppress ethylene biosynthesis across multiple species, further extending postharvest life (Mortazavi *et al.,* 2011). There are some new generation growth regulators which improve the postharvest life and attributes of flowers (Table 1).

Storage, packaging and transportation

Temperature is the most critical factor in maintaining flower quality during storage (Jain *et al.* 2011). Lower storage temperatures decrease respiration, reduced water loss metabolic activity, ethylene synthesis, and disease development, increasing post-harvest durability (Cevallos and Reid, 2001). Cold storage of cut flowers can be done by wet or dry methods. Wet storage, where stems are kept in water, is suitable for short durations, while dry storage allows longer storage and space efficiency but is more labour-intensive and not suitable for all flowers. Key factors such as temperature, relative humidity, air composition, and circulation significantly influence postharvest quality (Cevallos and Reid, 2001). Controlled atmosphere storage, involving low O_2, elevated CO_2, and reduced ethylene, helps delay senescence by slowing respiration.

Verma *et al.,* (2006) reported that, dry storage of chrysanthemum cv. Snow Ball showed that wrapping flowers in wax paper and storing them under cold conditions for 24 hours resulted in maximum vase life, better flower size, higher sugar content, and minimal

Table 1: New generation plant growth regulators and their mode of action

Growth regulator	Mode of action	Examples	Reference
Salicylic acid	1. It has a pH of 2.4 and acidic solution inhibits bacteria growth and proliferation. 2. Modulate plant responses to a wide range of oxidative stresses and prevents cell wall degradation. 3. SA suppresses ACC synthase and ACC oxidase activities, biosynthesis of ethylene, and improves the postharvest life.	Alstroemeria, *Lilium, Rose, Gerbera* and *Tuberose*	Bayat and Aminifard, 2017
Polyamines (Putrascine, Spermine and Spermidine)	Role in sugar biosynthesis, Stimulation of cell division, maintains integrity of cell membrane and delays senescence. Free radical scavenger, increases water uptake, high retention of fresh weight and p*etal* sugar status, low electrolyte leakage.	Rose, gerbera, carnation, lilium etc	Sumathi *et al.,* 2015
Nitric oxide (sodium nitroprusside) as Nitric oxide) donor	Endogenous plant signal molecule, decreased 1-aminocyclopro-pane-1- carboxylate oxidase (ACO) activity and ethylene production. Hormone modulation, programmed cell death and wounding and defense responses	Rose, carnation	Mortazavi *et al.,* 2011
Thiodiazuron (N-phenyl-N-l, 2, 3-thiadiazol-5-Urea)	Non-metabolized Cytokinin, promote the conversion of cytokinin ribonucleotides to more biologically active Ribonucleosides, strong cytokinin-like activity, prevent leaf senescence	Alstroemeria, stock, lilies, tulips and potted plants, including geranium, freesia, Ornithogalum, and *Euphorbia fulgens*	Macnish *et al.,* 2010

weight loss. Controlled atmosphere storage further delays senescence by modifying gas composition, although its adoption is limited due to cost constraints (Nowak and Rudnicki, 1990). Modified atmosphere packaging (MAP), which uses semi-permeable plastic films, has limited application in cut flowers due to its requirement for consistently low temperatures, though it can extend the life of crops like carnations. In contrast, Modified Interactive Packaging (MIP) is more adaptable, as gas composition inside the package adjusts dynamically based on temperature and flower maturity. MIP offers greater temperature tolerance and reduces transpiration by maintaining high relative humidity. It slows flower metabolism through slight increases in CO_2 and reduced O_2 levels, thereby extending postharvest life. This makes MIP particularly useful for long-distance transport, including sea shipment, or for storage before peak demand periods such as Valentine's Day (Bishop, 2007).

Packaging materials play a protective role against mechanical damage and moisture loss, though environmental concerns regarding synthetic materials are increasing (Ahvenainen, 2003). Cellophane wrapping was most effective in maintaining postharvest quality of rose cv. First Red. Flowers wrapped in cellophane and stored at 2°C for 3 days showed improved vase life, higher water uptake, better flower size, greater retention of proteins and sugars, and minimum weight loss compared to other treatments. (Jain *et al.,* 2006). Packaging significantly affects the postharvest quality of loose tuberose cv. Arka Prajwal. Among the treatments, HDPE (51 µm) packaging performed best, especially under cold storage and also improved quality under ambient conditions compared to control.

Overall, HDPE bags were most effective in extending shelf life and maintaining flower quality (Singh *et al.,* 2024). Shrink-wrap (Cryovac®) and HDPE packaging were most effective, extending shelf life of African marigold cv. Pusa Bahar up to ~19 days under cold storage and 4.5 days under ambient conditions. Shrink-wrap also maintained key quality attributes (moisture, color, membrane stability, and antioxidants) while reducing weight loss and respiration. Improved antioxidant enzyme activity (SOD, CAT, POD) contributed to delayed senescence, making shrink-wrap the most effective packaging method (Viresh *et al.,* 2024). Similarly, shrink-wrap proved most effective, for extending its post-harvest life and quality attributes in both African and French marigold cultivars, suggesting its strong potential for commercial adoption to enhance marigold storability and reduce post-harvest losses (Kumar *et al.,* 2025).

Transportation remains a critical limitation, as lack of refrigerated systems leads to rapid quality deterioration (Wills, 1998). Road and air transport are the primary modes for moving cut flowers (Nowak and Rudnicki, 1990). Refrigerated trucks are used for regional transport, while air transport is preferred for long-distance shipping, sometimes supplemented with ice or dry ice to manage heat load (Wills, 1998). In the absence of cooling, proper ventilation helps reduce respiration heat and ethylene buildup. Rail and refrigerated sea containers also offer viable options, particularly for durable flowers like bud-stage carnations under controlled atmosphere (CA) conditions (Macnish *et al.,* 2009). Maintaining the cold chain is critical; re-cooling and rehydration—by re-cutting stems and placing them in treated water—help preserve postharvest quality during handling and distribution.

Cold chain management (CCM)

Effective CCM begins at the farm and continues until the product reaches the final consumer, making it a key strategic advantage in the floriculture industry. It requires strict temperature regulation and prompt corrective actions in case of delays or temperature fluctuations. Maintaining optimal temperature at every stage of the supply chain is essential to preserve product quality (van der Hulst, 2004). Research indicates that even a single temperature excursion above 10°C during transit can reduce vase life by 2–3 days for sensitive crops like roses and gerberas, highlighting the importance of uninterrupted cold chain maintenance (Staby and Reid, 2005). However, temperature variations during handling and transportation can still reduce its efficiency (Staby and Reid, 2005). Studies have shown that storing loose marigold flowers at low temperatures can extend shelf life up to twofold (Viresh *et al.,* 2024; Kumar *et al.,* 2024). Similarly, cold storage of loose tuberose cv. Arka Prajwal significantly improves postharvest attributes such as flower diameter, opening, color retention, and extends shelf life up to six days (Singh *et al.,* 2024).

Value- addition

Value-addition in floriculture significantly enhances economic returns by transforming highly perishable raw flowers into diversified, high-value products with improved marketability (Vijay and Baweja, 2025). Such interventions, including drying, extraction, and processing, convert low-value produce into premium commodities, thereby increasing overall profitability of the floriculture enterprise (Shah *et al.,* 2022). Farmers and entrepreneurs can achieve substantial profit enhancement—often ranging from 50% to 100%—as value-added products such as essential oils, dried flowers, floral crafts, and edible derivatives fetch higher prices than fresh flowers in conventional markets (Koushal *et al.,* 2024). For example, essential oil extraction from rose petals in Kannauj, India, yields return 3–5 times higher than fresh flower sales at wholesale markets, while dried statice and gomphrena products fetch 2–3× the fresh flower price in export markets (Shah *et al.,* 2022). Furthermore, value- addition reduces dependence on volatile fresh flower markets and helps stabilize income during periods of oversupply and price crashes (Vijay and Baweja, 2025).

Another important economic advantage is the development of off-season and shelf-stable products through value-addition (Koushal *et al.,* 2024). Since fresh flowers have a limited vase-life and high perishability, processing techniques such as dehydration, freeze-drying, and extraction extend their usability and market availability (Sindhu and Gupta, 2024). Shelf-stable products like potpourri, essential oils, natural dyes, and nutraceuticals enable year-round marketing and facilitate access to export markets, thereby increasing overall value chain efficiency (Koushal *et al.,* 2024). In addition, improved postharvest technologies contribute to quality retention and extended storage life, further enhancing economic returns from floricultural produce (Harish *et al.,* 2026).

Value-addition also contributes significantly to waste minimization and supports the concept of a circular economy in floriculture systems (Tiwari and Bisen, 2024). A considerable proportion of flowers estimated at around 30–40% is lost due to perishability and inadequate postharvest handling practices (Tiwari and Bisen, 2024). These floral wastes can be effectively utilized for producing value-added products such as biofertilizers, essential oils, natural pigments, incense sticks, and bioenergy, thereby converting waste into economic resources (Dutta *et al.,* 2021). This approach aligns with circular bioeconomy principles, where biological waste streams are recycled into productive uses, reducing environmental burden and generating additional income opportunities (Kumar *et al.,* 2025). Moreover, such sustainable utilization of floral biomass promotes rural entrepreneurship, employment generation and efficient resource utilization in the floriculture sector (Koushal *et al.,* 2024).

Natural essential oils are volatile aromatic compounds extracted from floral, foliar, stem, and woody plant tissues through steam distillation, cold pressing, or solvent extraction. Their applications span aromatherapy, cosmetics, perfumery, and pharmacological uses owing to their antioxidant, antimicrobial, and anxiolytic properties (Lobo *et al.,* 2022). India's fragrance market is rapidly growing, projected to rise from $1.25 billion in 2025 to nearly $2 billion by 2034, with the attar segment expanding even faster due to its natural and cultural appeal. Attars, being alcohol-free and made from natural flowers like rose and jasmine, are valued for their long-lasting fragrance, skin-friendliness, and are increasingly positioned as premium wellness and luxury products (Aroma Craft Blog March 29, 2026).

Tinted flowers often fetch higher prices in the market as they enhance visual appeal and allow the addition of one or more attractive colours to cut flowers, thereby increasing their aesthetic value. In crops like tuberose, tinting serves as an effective value-addition technique alongside its natural fragrance. Studies have shown that use of edible dyes, particularly raspberry red, can improve vase life, reduce floret drying, and enhance overall consumer acceptance (Jain *et al.,* 2015). Similarly, research on chrysanthemum, tuberose, and lilium indicates that dye type and immersion duration significantly affect vase life, moisture content, and colour quality, with blue, green, and orange dyes providing better colour intensity and consumer preference, while optimal immersion time helps maintain freshness and longevity (Pavan *et al.,* 2022). It is important to note that dyes intended for fresh flower tinting must comply with food safety regulations (FSSAI in India; FDA in the US) when flowers are destined for culinary or medicinal use, necessitating careful selection of approved colorants.

Eco-friendly dry flower products have great potential, especially in cold regions where fresh flowers are scarce. Proper drying of long-lasting flowers helps retain their color and quality, increasing their value in markets. These products are often profitable, depending on costs, finishing, packaging, and shelf life. Flowers like statice, gomphrena, rose, sunflower, and zinnia are ideal as they remain attractive after drying. Using protective methods such as lamination or plastic coverings helps prevent insect and fungal damage while preserving their natural appearance, making them more appealing to buyers (Singh and Kumari, 2023.) Embedded drying of roses using silica gel combined with a hot air oven is widely reported as an effective preservation method. Bhutani (1990) and Datta (2004) have shown that embedding flowers in desiccants like silica gel helps maintain shape and absorb moisture, while controlled oven drying improves color retention and overall quality.

This technique is therefore commonly recommended for producing high-quality dried rose products. Vacuum drying is the most effective method for preserving color, texture, and overall quality of *Gerbera hybrida* 'Ruby Red' dried flowers. However, microwave drying helps retain flower size, vacuum drying gives the best overall results for long-term preservation (Namita *et al.,* 2018). Techniques such as glycerin drying have proven effective in preserving foliage quality and enhancing product appeal. A ratio of 1:3 (glycerin-to-water) was found to be most suitable for preserving foliage like silver oak, asparagus, cordyline, and fern, as it ensured better moisture retention, quicker drying, and improved overall quality (Singh *et al.,* 2018). Natural dye extraction from flowers offers eco-friendly alternatives for textile and food industries, but challenges remain in improving stability and scalability.

There is a growing shift from synthetic dyes to natural pigments due to health concerns like toxicity and carcinogenic effects, along with increasing consumer demand for safe and eco-friendly products. Natural dyes offer added benefits such as antioxidant, antimicrobial, and nutritional properties, though they can be more expensive and may affect flavour or aroma (Mohammad *et al*, 2022). Keerthana *et al.,* (2026) optimized anthocyanin extraction from rose petals using Response Surface Methodology, finding maximum yield under mild acidic conditions (0.014–0.015% HCl), low temperature (25°C), and a 1:5 ratio. It also showed that the pigment is most stable at low temperatures, acidic pH (1–3), and dark storage, while heat, light, and alkaline conditions accelerate degradation.

Emerging Trends

Nanotechnology and bio-based coatings

Nanotechnology-based coatings have shown potential in reducing transpiration and microbial growth, thereby improving postharvest quality (Sharma *et al.,* 2025). Silver nanoparticles (AgNPs, 10–50 nm) inhibit microbial growth at cut stem surfaces and reduce xylem blockage, while titanium dioxide (TiO_2) coatings lower ethylene-mediated senescence through photocatalytic degradation of ethylene under light exposure. Zinc oxide (ZnO) nanoparticles have additionally shown ROS-scavenging activity, synergizing with antioxidant-based postharvest treatments (Sharma *et al.,* 2025). Eco-friendly preservatives derived from plant extracts are gaining attention as sustainable alternatives (Bhandari *et al.,* 2026).

Smart packaging digital supply chain and genetic engineering

Smart packaging and IoT-based monitoring systems enable real-time tracking of storage conditions, improving supply chain efficiency (Rashed *et al.,* 2024). Several advanced methods, including physical, chemical, and emerging treatments like nanoparticles, melatonin, and essential oils, have been developed to enhance flower freshness. Recent advances in physical treatments (e.g. LED light, ozone, gamma radiation) and the application of bioactive compounds like melatonin, polyamines, and essential oils offer promising results in improving flower longevity (Jain *et al.,* 2025). Genetic engineering offers a promising avenue for developing senescence-tolerant varieties through targeted suppression of ethylene biosynthesis genes (ACS/ACO) or overexpression of antioxidant genes, thereby inherently extending postharvest longevity.

Environment-friendly practices

In flower processing, environmentally friendly practices are becoming increasingly important.

Eco-friendly extraction methods, such as the use of natural solvents or organic techniques, help minimize environmental impact, while zero-waste approaches ensure that all parts of the flower—petals, stems, and leaves—are utilized efficiently, reducing waste. Additionally, the use of biodegradable or recyclable packaging supports sustainability and meets the growing consumer demand for eco-conscious floral products [Shobna *et al* 2023]. Cold-pressed essential oils are widely used in high-end perfumes, luxury cosmetics, and aromatherapy because they retain the natural aroma and purity of the flowers. This method preserves volatile compounds, resulting in a richer and more complex fragrance profile, making the oils highly suitable for wellness and therapeutic applications. (Lobo *et al*, 2022).

CONCLUSION

Postharvest management of ornamental crops involves a complex interaction of physiological, biochemical, and environmental factors that determine flower quality and longevity. Although advancements have been made in understanding respiration, ethylene action, water relations, and oxidative stress, their integrated management remains challenging. Improved harvesting, handling, cold chain systems, and advanced storage and packaging can significantly reduce losses, but limitations in infrastructure and standardization persist. Value-addition further enhances profitability by converting perishable flowers into high-value products such as essential oils, dried flowers, natural dyes, and tinted blooms. This not only increases market value but also ensures income stability and year-round utilization.

The integration of sustainable practices, eco-friendly technologies, and innovations like smart packaging and bio-based treatments highlights the strong potential of floriculture for economic growth, environmental sustainability, and rural entrepreneurship. Future research priorities should include: (i) development of integrated postharvest management protocols combining physiological, chemical, and physical interventions specific to major ornamental crops; (ii) techno-economic analysis of value-addition supply chains to identify cost-effective entry points for smallholder farmers; (iii) field validation of nanotechnology-based and bio-based preservatives under Indian agroclimatic conditions; and (iv) use of omics approaches (transcriptomics, metabolomics) to identify novel senescence-related molecular targets for genetic improvement of vase-life.

REFERENCES

Ahmad, I., Dole, J. M., and Blazich, F. A. 2014. Effects of daily harvest time on postharvest longevity, water relations and carbohydrate status of selected specialty cut flowers. *HortScience* **49**(3): 297–305.

Ahvenainen, R. (Ed.). 2003. *Novel food packaging techniques*. CRC Press, New York.

Aroma Craft. 2026. Indian attar market 2026: Tradition meets modern luxury. Retrieved from https://aromacraftindia.com/indian-attar-market-2026-tradition-meets-modern-luxury/

Baron, F., Mendoza, R., Melo, S., Clavijo, J., and Castellanos, D.A. 2021. Evaluation and representation of ethylene effect on vase life and quality of rose (*Rosa hybrida* cv. Vendela). *Acta Physiologiae Plantarum* **43**: 161.

Bayat, H., and Aminifard, M. H. 2017. Salicylic acid treatment extends the vase life of five commercial cut flowers. *Electronic Journal of Biology, **13***(1): 67–72.

Bhandari, P., Sharma, R., and Singh, D. 2026. Biotechnological approaches for eco-friendly flower preservation. *Journal of Horticultural Science and Biotechnology* **101**(1): 45–58.

Bhutani, S. S. 1990. Drying of flowers with silica gel. *In:* Postharvest Handling and Storage of Cut Flowers. R. M. Rudnicki and J. Nowak (Eds.), Timber Press Portland, Oregon, pp. 115–22.

Bishop, C. F. H., Gash, A. J., Mathas, E., and Finlayson, I. 2007. Use of modified packaging with cut flowers. *Acta Horticulturae* **755**: 515–18.

Cevallos, J. C., and Reid, M. S. 2001. Effect of temperature on flower storage and vase life. *Hort Technology* **11**(2), 199–202.

Datta, A. 2004. Drying techniques for cut flowers: Silica gel and oven methods. *In:* Advances in Ornamental Horticulture Sen, S. K. (Ed.), pp. 213–22.

Dutta, S., and Kumar, M. S. 2021. Potential of value-added chemicals extracted from floral waste: A review. *Journal of Cleaner Production* **294**:126280.

Faust, J. E., and Dole, J. M. 2021. The global cut flower and foliage marketplace. *Cut Flowers and Foliage, **27***: 1–47.

Halevy AH and Mayak S 1979. Halevy AH and Mayak S 1979. The role of plant-water relations in the quality of cut flowers. In: Janick J and Simon JE (Eds.), *Horticultural Reviews* **1**: 204-31.

Halevy AH and Mayak S 1981. Senescence and postharvest physiology of cut flowers. *In:* Janick J and Simon JE (Eds.), *Horticultural Reviews* **2:** 59–143.

Harish, T., Sulankhe, N., and Pavankumar, M. 2026. Postharvest technologies of shelflife extension in cut flowers. *Archives of Current Research International* **26**(1): 193–205.

Hoppen, C. 2020. *Functional and structural characterization of copper chaperones interaction with ethylene receptors* (Ph D thesis). Heinrich-Heine-University.

Jain, R., and Janakiram, T. 2016. Effect of aluminium sulphate and citric acid on postharvest qualities of spray chrysanthemum (*Dendranthema × grandiflora*). *Current Horticulture* **4**(1): 42–7.

Jain, R., Bhalla, R., and Dhiman, S. R. 2007. Effect of pulsing treatments on postharvest life of rose cv. First Red. *Journal of Ornamental Horticulture* **10**(3):143–47.

Jain, R., Bhalla, R., Gupta, Y. C., Thakur, K. S., and Thakur, R. 2006. Effect of wrapping material and dry storage on postharvest quality of rose cv. First Red. *Journal of Ornamental Horticulture* **9**(3): 192–95.

Jain, R., Singh, K. P., and Namita. 2011. Effect of storage temperature and packing materials on display life of tuberose loose flowers. *In: Abstract book of National Conference on Floriculture, held at Meerut*, pp. 174–75.

Jain, R., Janakiram, T., and Kumawat, G. L. 2015. Studies on postharvest attributes of tuberose cultivars as influenced by tinting with edible colours. *Current Horticulture* **3**(2):18–24.

Jain, R., Janakiram, T., Singh, K. P., and Kumawat, G. L. 2014. Reduction of foliage discoloration and extending vase life of chrysanthemum with different floral preservatives. *Indian Journal of Agricultural Sciences* **84**(10): 1250–53.

Jain, R., Varun, M. H., Raghavendra, H. R., Lava Kumar, D., Madhavi, K., Vamsi, M., Tiwari, A. K., Singh, B., Kumar, N. M., and Pooja, A. 2025. Preservation of freshness in flowers: A review of post-harvest challenges and solutions. *Indian Journal of Agricultural Sciences* **95**(10): 1147–55.

Jain, R., Kumar, P., Singh, B., Varun, M. H., and Tiwari, A. K. 2021. Efficacy of 5-sulpho salicylic acid as a substitute for 8-hydroxyquinoline citrate for prolonging vase life of gladiolus spikes. *Indian Journal of Agricultural Sciences* **91**(12): 1793–95.

Jain, R., Varun, M. H., and Lakshmi, D. 2018. Post harvest management of ornamental crops. *In: Global Hi-Tech Horticulture*, S. Tyagi (Ed.), ***6*:**1113–39.

Jones, R. B., and Hill, M. 1993. The effect of germicides on the longevity of cut flowers. *Postharvest Biology and Technology* **3**: 343–50.

Kader, A. A. 2002. Postharvest Biology and Technology: An Overview, *In: Postharvest Technology of Horticultural Crops* (3rd. edn.). UC Davis pp.39-49.

Keerthana, S., Singh, B., Jain, R., Singh, M. K., Tiwari, A. K., Joshi, A., and Bansal, R. 2026. Optimization of extraction and stability characterization of rose petal natural dye: A standardized approach. *Journal of Environmental Biology* **47**(2): 254–62.

Shibuya, K., Yamada, T., and Ichimura, K. 2016. Morphological changes in senescing petal cells and regulatory mechanism. *Journal of Experimental Botany* **67**(20): 5909–18.

Koushal, S., Sarvade, S. A., Lohar, A., Kaushik, K., Reddy, C. S., and Yampalla, M. 2024. Value addition in floriculture: Potential of flower processing and by-products. *International Journal of Advanced Biochemistry Research* **8**(11): 523–29.

Kumar, M. N., Jain, R., Singh, M. C., Tiwari, A. K., Singh, B., Sethi, S., Sathee, L., Lal, K., Kumar, A., and Madhavi, K. 2024. Evaluation of packaging materials for enhancing storage life of marigold (*Tagetes erecta*). *Indian Journal of Agricultural Sciences* **94**(2):192–97.

Kumar, M. N., Jain, R., Singh, M. C., Tiwari, A. K., Singh, B., Sethi, S., Sathee, L., and Lal, K. 2025. Evaluation of packaging materials for enhancing storage life of marigold (*Tagetes erecta*). *Indian Journal of Horticulture* **94**(2):192–97.

Verma, A. K., Gupta, Y. C., Dhiman, S. R., and Jain, R. 2006. Effect of dry storage on postharvest quality of chrysanthemum (*Dendranthema grandiflora* cv. Snow Ball). *Journal of Ornamental Horticulture* **9**: 20–24.

Lobo, M. G., and Dorta, E. 2019. Utilization and management of horticultural waste. *In: Postharvest Technology of Perishable Horticultural Commodities*. Elhadi M. Y. (Ed.). Woodhead Publishing, Cambridgeshire, U K. 639–66 pp.

Ma, N., Ma, C., Liu, Y., Shahid, M. O., Wang, C., and Gao, J. 2018. Petal senescence: A hormone view. *Frontiers in Plant Science* **9**: 1433.

Macnish, A. J., Jiang, C. Z., and Reid, M. S. 2010. Thidiazuron improves opening and vase life of iris flowers. *Postharvest Biology and Technology* **56**(1): 77–84.

Mohammad Azmin, S. N. H., Sulaiman, N. S., Mat Nor, M. S., *et al.* 2022. Natural plant pigments in foods: Functions and challenges. *Applied Biochemistry and Biotechnology* **194**: 4655–72.

Mortazavi, S. N., Talebi, S. F., Naderi, R. A. and Sharafi, Y 2011. Regulation of ethylene biosynthesis during postharvest of rose. *Journal of Medicinal Plants Research* **5**(25): 5177–83.

Namita, Jain, R., Janakiram, T., Singh, P. L., Sindhu, S. S., Panwar, S., and Pinder, R. 2018. Optimization of dehydration techniques for gerbera cv. Ruby Red. *Chemical Science Review and Letters* **7**(27): 796–800.

Nergi, M. A. D., and Ahmadi, N. 2014. Effects of 1-MCP and ethylene on postharvest quality of rose cv. Sparkle. *Scientia Horticulturae* **166**: 78–83.

Nowak, J., and Rudnicki, R. M. 1990. *Postharvest handling and storage of cut flowers*. Timber Press. Portland, Oregon

Pavan, N. Kukanoor, R., Gorabal, L., Patil K., Shiragur, S. R., M., and Koulagi, S. 2022. Standardization of tinting techniques in chrysanthemum, tuberose and *Lilium*. *Pharma Innovation Journal* **11**(4): 713–17.

Pun, U. K., and Ichimura, K. 2003. Role of sugars in senescence and ethylene biosynthesis in cut flowers. *JARQ* **37**(4):219–24.

Rani, P., and Singh, N. 2014. Senescence and post-harvest studies of cut flowers: A review. *Pertanika Journal of Tropical Agricultural Science* **37**(2): 58–63.

Rashed, M., Li, X., and Zhang, Y. 2024. Digital tracking and smart cold chain integration in floriculture supply chains. *Frontiers in Plant Science* **15**:1371100.

Reid, M. S. 1989. Ethylene and flower senescence. *Acta Horticulturae* **261*:*** 89–100.

Reid, M. S., and Jiang, C. Z. 2012. Postharvest biology of cut flowers and potted plants. *Horticultural Reviews* **40** :1–54.

Rudnicki, R. M., Nowak, J., and Goszczynska, D. M. 1991. Cold storage and transport of cut flowers. *Acta Horticulturae* **298** :225–36.

Shah, A. H., Singh, A., Laishram, N., and Gill, K. 2022. Income generation through value addition of flower crops. *International Journal of Environment and Climate Change* **12**(10): 593–613.

Sharma, A., Thakur, A., Sharma, A., Thakur, M., Sharma, S., Sharma, H., Thakur, R., Thakur, D., and Suhag, R. 2025. Nano-edible coatings for shelf-life extension. *Journal of Food Science and Technology* **62**: 397–412.

Siddiqui, M. W. (Ed.). 2015. *Postharvest Biology and Technology of Horticultural Crops*. CRC Press, New York

Singh, B., Jain, R., Sindhu, S. S., Yadav, H., and Kumar, R. 2019. Godetia: A natural source of dye. *Indian Horticulture* **64**(1) :14–15.

Singh, B., Jain, R., Sindhu, S. S., Kumar, P., and Harender. 2018. Standardization of glycerine preservation for foliage. *Indian Journal of Agricultural Sciences* **88**(12) :1879–86.

Singh, D., and Kumari, P. 2023. Quality and economics analysis of dry flower products. *Annals of Agricultural Research* **44**(2): 249–53.

Singh, K. P., Priya, B. B., and Jain, R. 2023. Influence of floral preservatives on tuberose. *Progressive Horticulture* **55**(2): 187–95.

Singh, K. P., Priya, B. B., and Jain, R. 2025. Changes in antioxidant enzymes in tuberose. *Plant Archives* **25**(2): 951–57.

Singh, A. K., Sisodia, A., and Pal, A. K. 2018. Value addition in floriculture: Scope and opportunities. *Indian Journal of Agricultural Sciences* **88**(2): 157–62.

Staby, G. L. and Reid, M. S. 2005. Advances in cold chain management of floricultural crops.

Tatte, S., Singh, A., and Ahlawat, T. R. 2016. Effect of polyamines on growth and flowering of rose. *Journal of Applied and Natural Science* **8**(3): 1317–20.

Taylor, R. D., Hill, J., and Grout, B.W.W. 2008. Irrigation regime and vase life of carnation. *Acta Horticulturae* **792*:*** 663–68.

Tiwari, V., and Bisen, A. 2024. New frontiers in post-harvest management of cut flowers. *International Journal of Agricultural Invention* **9**(2) 227–30.

Tripathi, P., and Dubey, N. K. 2004. Natural products for postharvest disease control. *Postharvest Biology and Technology* **32**(3): 235–45.

van der Hulst, J. 2004. Cool chain management for cut flowers. *Flower Tech* **7**(6): 49–51.

van Doorn, W. G. 1997. Water relations of cut flowers. *Horticultural Reviews* **18*:*** 1–85.

van Doorn, W. G., and Cruz, P. 2000. Xylem occlusion in senescence of cut flowers. *Postharvest Biology and Technology* **19**(2): 153–58.

Varu, D. K., and Barad, A. V. 2007. Effect of harvest date on vase life of tuberose. *Journal of Horticultural Science* **2**(2): 148–52.

Varun, M.H, Jain, R., Jain, N., Arora, A., Singh, K. S. M., Kumar, P., and Kumar, G. 2018a. Delaying senescence in chrysanthemum. *Indian Journal of Horticulture* **75**(3): 506–11.

Varun, M.H, Jain, R., Jain, N., Arora, A., Singh, K. S. M., Kumar, P., and Kumar, G. 2018b. Endogenous ascorbic acid in chrysanthemum. *Indian Journal of Agricultural Sciences* **88**(9): 1429–33.

Varun, M. H., Jain, R., and Sinha, N. 2019. Effect of exogenous ascorbic acid application on vaselife and biochemical constituents of chrysanthemum (*Chrysanthemum × morifolium*). *Indian Journal of Agricultural Sciences* **89**(9): 1498–502.

Vijay, J., and Baweja, H. S. 2025. Value addition in floriculture: A review. *Journal of Ornamental Horticulture* **28**(1): 9–19.

Viresh, M. B., Jain, R., Sethi, S., *et al.* 2024. Cryovac-based shrink wrap packaging for marigold. *Acta Physiologiae Plantarum* **46*:*** 117.

Wills, R. H. B. 1998. *Postharvest: An Introduction to the Physiology and Handling of Fruit, Vegetables and Ornamentals*. CABI Publishing. UNSW Press, 262p.