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REVIEW ARTICLE

Recent approaches to enhance post-harvest handling of cut flowers for global export market

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Abstract

The global floriculture industry, particularly the trade in cut flowers, has witnessed significant growth over recent decades, becoming a vital component of agricultural exports for many nations. However, cut flowers are highly perishable commodities, highly susceptible to physiological deterioration, microbial contamination and abiotic stresses post-harvest. Effective postharvest handling is essential to preserve quality attributes such as colour, turgidity, scent and vase life parameters critical for consumer satisfaction and marketability. This review explores recent scientific and technological advances in postharvest handling practices aimed at enhancing flower longevity and ensuring competitiveness in international markets. Topics include the use of chemical preservatives, ethylene inhibitors and genetic improvements; advances in microbial control using UV-C, ozone and essential oils; integration of automated grading systems using AI and machine vision; and the adoption of innovative, sustainable packaging solutions including biodegradable materials, smart packaging and Modified Atmosphere Packaging (MAP).

Keywords: advances; challenges; cut flowers; postharvest; quality; trade

Introduction

The global cut flower trade has become one of the most vibrant and economically significant segments of horticulture, with countries like the Netherlands, Colombia, Kenya and Ecuador leading the international export market (1). These nations collectively supply billions of cut flower stems each year to high-demand regions such as Europe, North America, Asia and the Middle East. Valued at over USD 35 billion annually, the floriculture industry not only contributes substantially to global agricultural exports but also provides essential employment opportunities, foreign exchange earnings and socio-economic support in many developing and middle-income countries (2). However, the industry faces persistent postharvest challenges that threaten product quality and profitability. Once harvested, flowers rapidly lose their vitality due to the cessation of nutrient and water uptake, making them highly susceptible to wilting, water stress, ethylene-induced senescence, microbial contamination and physical damage (3). Factors such as microbial blockage in stem xylem, poor handling practices, mechanical injuries during grading and temperature fluctuations during storage and transport further exacerbate postharvest losses, which can reach up to 30 % in certain regions, particularly where cold chain infrastructure is lacking (4). In light of these challenges, this article aims to explore and consolidate recent innovations and sustainable practices in postharvest handling of cut flowers (fig. 1). Emphasis is placed on emerging technologies, environmentally friendly solutions and improved logistics that collectively aim to extend flower shelf life, reduce waste and enhance market competitiveness (5). Ultimately, this article seeks to guide researchers, policymakers, exporters and supply chain stakeholders toward integrated strategies that promote quality preservation and long-term sustainability in the global floriculture value chain.

Extending postharvest longevity

Enhancing postharvest longevity is a critical aspect of maintaining the commercial quality of cut flowers destined for global markets and this involves a multi-faceted approach cantered on physiological preservation, ethylene inhibition, environmental control and genetic improvement (6). One of the primary strategies involves the use of preservative and pulsing solutions,

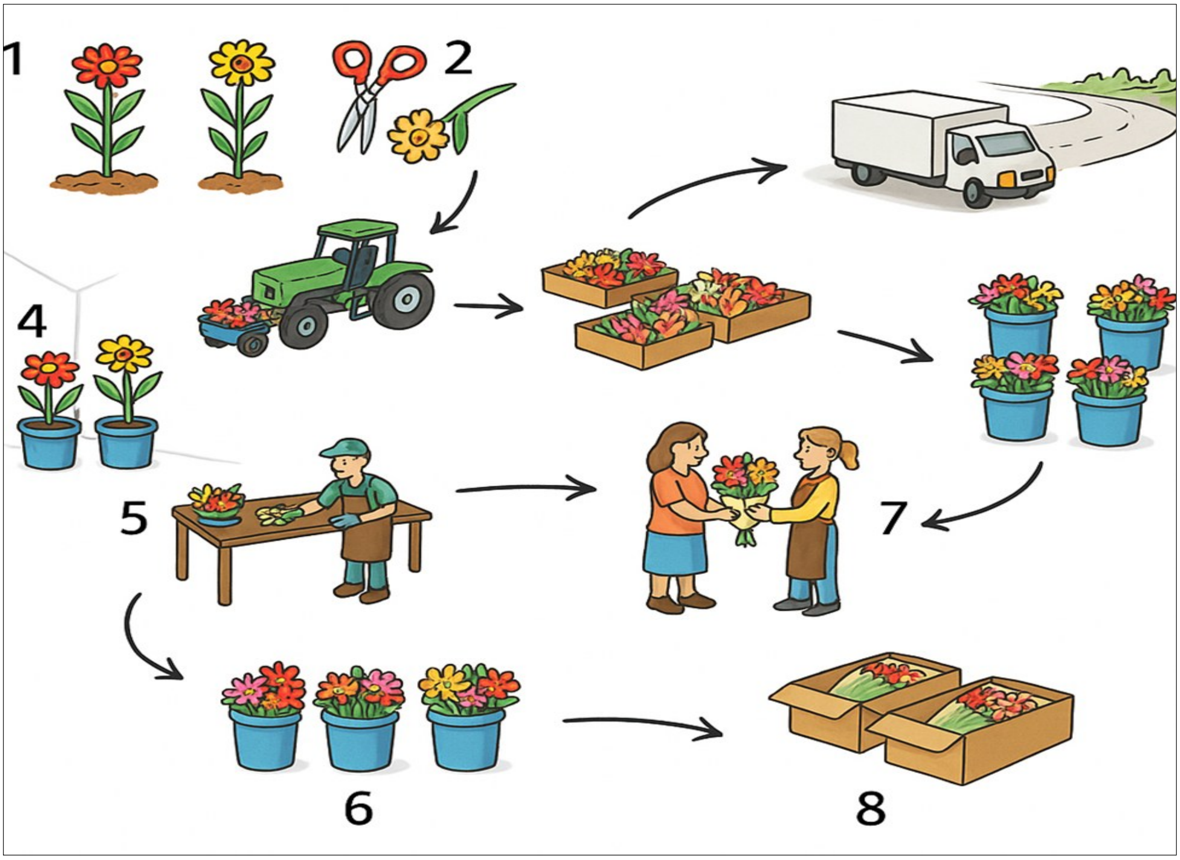

Fig. 1. Post harvest chain of cut flowers.

which typically comprise a combination of carbohydrates (such as sucrose), antimicrobial agents (like 8-hydroxyquinoline citrate [8-HQC] or silver nitrate) and growth regulators (such as cytokinins, gibberellic acid or auxins) to enhance flower longevity and quality (7). These components serve to provide respiratory substrates for the flowers, promote bud opening, maintain osmotic balance and inhibit microbial growth that could block xylem vessels and reduce water uptake (8). Pulsing treatments, conducted within 12 to 24 hours post-harvest, involve immersing cut stems in concentrated solutions often containing 10 %–20 % sucrose and 200–300 ppm 8-hydroxyquinoline citrate (8-HQC) to fortify them against transit stress (9).While silver thiosulfate (STS) has been widely used for its effectiveness in ethylene inhibition, regulatory restrictions due to its heavy metal content have prompted a search for safer alternatives, including nano-silver, citric acid and biodegradable plant-based biocides (10). Ethylene inhibition is particularly vital for ethylene-sensitive species such as carnations, orchids and sweet peas, which are prone to rapid senescence due to exposure to endogenous or exogenous ethylene (11). The use of 1-Methylcyclopropene (1-MCP), a synthetic compound that binds irreversibly to ethylene receptors, has revolutionized postharvest ethylene management by preventing typical symptoms like petal wilting, chlorophyll breakdown and premature flower drop (12). Technological advancements have further refined its application through microencapsulation and gaseous formulations that can be deployed across entire storage containers. In tandem, optimal temperature and humidity control is fundamental to prolonging freshness. Ideal storage temperatures generally range from 0 °C to 5 °C, depending on species sensitivity, while maintaining high relative humidity (90 %-95 %) is essential to minimize water loss (13). Pre-cooling within 2 to 4 hours post-harvest is crucial to arrest metabolic activity and delay senescence (14). Maintaining hydration through acidified water solutions, wet floral foams or hydration gels during packaging is especially important for flowers subjected to long-distance shipping (15). Complementing these physical and chemical strategies, genetic improvement has emerged as a promising long-term approach. Through advanced molecular breeding techniques, researchers are developing cultivars with delayed senescence, reduced ethylene sensitivity and improved water transport efficiency for instance, miniature rose *Rosa hybrida* 'Linda', transformed with the P(SAG12)-ipt gene, shows delayed leaf senescence and greater resistance to exogenous ethylene. Similarly, in ornamental petunia, transformation with etr1-1 a dominant ethylene-insensitive allele from *Arabidopsis* under floral-specific promoters extended vase life up to fivefold. Moreover, expressive overexpression of regulatory genes such as FOREVER YOUNG FLOWER (FYF) in *Eustoma grandiflorum* has also delayed senescence by down-regulating key ethylene pathway genes. Innovations such as Quantitative Trait Loci (QTL) mapping for vase life traits, CRISPR/Cas9-mediated gene editing to suppress ethylene biosynthesis genes and RNA interference (RNAi) for gene silencing are showing significant potential in commercially important species like roses, gerberas and chrysanthemums. Together, these integrated strategies contribute to preserving the aesthetic and physiological quality of cut flowers throughout the supply chain, enhancing their appeal and shelf life in competitive export markets.

Postharvest Disease and Microbial Management

Postharvest diseases pose a significant threat to the quality and marketability of cut flowers, often resulting in aesthetic damage, reduced vase life and substantial economic losses (16). Among the most prevalent pathogens is *Botrytis cinerea*, a fungal organism responsible for grey mold that appears as fuzzy, greyish lesions on petals and buds, especially under high humidity conditions. *Erwinia carotovora*, a bacterial pathogen, causes soft rot in floral tissues, leading to tissue collapse and foul odour, while *Pseudomonas fluorescens* is known to interfere with water uptake by colonizing and blocking the xylem vessels of cut stems (17). These infections typically arise due to a combination of high moisture levels, inadequate sanitation and physical injuries incurred during harvesting, grading or transport. To mitigate these issues, several disinfection strategies have been developed and are increasingly incorporated into postharvest protocols (18). UV-C radiation, which employs short-wave ultraviolet light, is effective in disrupting microbial DNA, thereby reducing surface contamination on floral tissues (19). Ozone treatment, leveraging the strong oxidative properties of O_3, serves as a residue-free sanitizer that decomposes back into oxygen, making it suitable for use in enclosed storage areas (20). Chlorine dioxide, particularly effective in gaseous form or in recirculated water systems, has demonstrated strong efficacy against a variety of pathogens, including the fungal agent *Botrytis cinerea* (gray mold) commonly afflicting cut roses, *Alternaria alternata* and *Stemphylium vesicarium* (targeted in postharvest treatments of tomatoes) and bacterial species such as *Escherichia coli*, *Salmonella typhimurium* and *Listeria monocytogenes* in produce systems (21). Additionally, plant-derived antimicrobials such as essential oils from thyme, clove and oregano have gained traction for their broad-spectrum antifungal and antibacterial properties, as well as their eco-friendly and biodegradable nature (22). Beyond chemical and physical treatments, maintaining strict hygiene throughout storage and handling operations is critical for disease prevention. This includes routine disinfection of storage bins, trimming tools and packaging materials, as well as ensuring that hydration water is sterilized and regularly changed to prevent biofilm buildup (23). Proper airflow and the prompt removal of decaying plant matter further help suppress pathogen proliferation (24). To standardize and strengthen these hygiene practices, some exporters have adopted the Hazard Analysis and Critical Control Points (HACCP) framework, allowing for systematic identification and control of microbial hazards in the postharvest phase. Together, these interventions form a comprehensive approach to microbial and disease management, preserving the visual and physiological quality of cut flowers and supporting their successful transit through global export supply chains.

Advanced Grading and Sorting Technologies

The grading and sorting of cut flowers, once a labor-intensive and subjective process, is being rapidly transformed by the integration of automation, artificial intelligence (AI) and machine vision technologies, particularly in high-throughput export-oriented facilities, enabling greater consistency, speed, labor savings and reduction of human error (25). These advanced systems use high-resolution cameras and image processing algorithms to assess critical floral attributes such as bud size and development stage, color intensity and uniformity, stem straightness, length and diameter, as well as to detect surface defects, deformities or signs of pest and disease infestation (26). AI-powered machine learning models continuously refine their accuracy by learning from vast datasets, enabling them to adapt to the natural variability in flower species and environmental conditions (27). This allows for real-time, high-precision classification and sorting of flowers according to predefined quality parameters (5). In addition, robotic arms integrated with AI are increasingly being deployed for the gentle handling and bunching of flowers, significantly reducing mechanical damage and enhancing efficiency (28). Grading parameters are typically aligned with international standards such as those set by the United Nations Economic Commission for Europe (UNECE), which emphasize uniformity, cleanliness and structural integrity for export-quality flowers. The implementation of automated grading not only ensures consistent quality and traceability but also reduces dependency on skilled labour, minimizes human error and accelerates processing time factors that are crucial for meeting the stringent timelines and quality expectations of global markets (29). This shift toward smart grading systems underscores the broader digital transformation within the floriculture industry, where precision, standardization and efficiency are paramount for maintaining a competitive edge in international trade.

Innovative and sustainable packaging solutions

The shift toward innovative and sustainable packaging solutions in the cut flower industry reflects growing global demand for environmentally responsible practices, especially in premium markets such as Europe and Japan (30). Traditionally, packaging for cut flowers has relied heavily on single-use, non-recyclable plastics, which contribute significantly to environmental pollution (31). In response, biodegradable alternatives are gaining traction, including polylactic acid (PLA) films derived from corn starch, starch-based bioplastics, banana fibre wraps and natural fibre sleeves made from jute and cotton (32). These materials not only reduce ecological impact but also enhance brand image and appeal to eco-conscious consumers, providing a marketing advantage in competitive export markets (33). Complementing this trend is the development of active and smart packaging technologies that extend flower freshness and improve supply chain monitoring (34). Active components such as ethylene scavengers typically potassium permanganate ($KMnO_4$) sachets and antimicrobial liners help mitigate ethylene accumulation and microbial growth within packaging, thereby prolonging shelf life (35). Smart labels, including Time-Temperature Indicators (TTIs) and RFID-enabled freshness tags, provide real-time data on temperature fluctuations and product condition during transit, enhancing traceability and allowing for more informed decisions in the supply chain (36). Another major innovation is Modified Atmosphere Packaging (MAP), which involves regulating the internal package environment specifically oxygen, carbon dioxide and humidity levels to slow down respiration rates, delay senescence and inhibit microbial proliferation. MAP is particularly valuable for long-haul shipments via sea freight, where prolonged transit times necessitate extended preservation (37). In parallel, modern packaging is being reengineered to integrate seamlessly with pre-cooling and hydration systems (38). Designs now include features such as ventilation holes for forced-air cooling, absorbent hydration wraps and breathable films that allow optimal airflow and moisture retention, all of which contribute to maintaining flower quality from farm to consumer (39) (Table 1). These integrated packaging strategies not only align with sustainability goals but also enhance logistical efficiency and postharvest performance, making them essential tools in the global export of cut flowers.

Table 1. Responses of plant species of cut flowers to different packaging and average storage life

S. No.	Crop	Type of package	Storage (hours/ days)	Temperature	Responses to package	Source
1.	Calendula	Passive modified atmosphere packaging (MAP) with microperforated film	10 days	5 °C	Overall (visual and nutraceutical) quality is good	(40)
2.	Carnation and snapdragons	MAP sealed with a gas permeable film	7 days	5 °C	Reduced weight loss and decay incidence and maintained visual quality	(41)
3.	Carnation, prairie gentian, chrysanthemum	Short-term controlled atmosphere	2h	5 °C and 23 °C	Prolong the vase life of ethylene sensitive flowers	(42)
4.	Cultivars of roses	Modified atmosphere plastic containers (7.09 kPa CO_2 and13.17 kPaO2)	10 days	2 °C	Flower quality was good	(43)
5.	Orchid	Active MAP, the orchid flowers were wrapped with MAP film filled with 5 % CO2 and 2 % O2	9.33 days		Flower size is longer	(44)
6.	Dendrobium orchids	Modified atmosphere packaging (5 % CO2, 2 % O2), Controlled atmosphere Normal package (NP)	28.33 days 18.15 days 11.67 days		Delaying the senescence	(44,45)
7.	Red Gala rose	The flowers were stored in controlled atmosphere (5 % CO2 and 4 % O2)	45 days	2 °C	Longer vase life	(45)
8.	Gerbera	Passive MAP	7 days	5 °C, 10 °C and 15 °C	Significantly lower physiological loss in weight; improved flower size, petal length and width during vase life	(46)
9.	Jasmine	Polypropylene packaging film for passive MAP	10 days	2 °C	Physiological reduction in weight loss	(47)
10.	Marigold Tagetes	Passive modified atmosphere packaging (with or without ethanol), when exposed to salinity (0,50 and100mMNaCl)		14 days	Flowers survived, increasing the levels of carotenoids and anthocyanins, making them potential nutraceuticals	(48)
11.	Marigold	Low-density polyethylene (LDPE) bags,	8 days of storage	23 °C	Significantly reduced weight loss and retained color and overall appearance	(49)
12.	Orchid	Passive MAP, polypropylene packaging, increase in CO2 and a decrease in O2 inside the packaging	15.66 days		Longest average storage life	(50)
13.	Ornithogalum spikes	Modified atmosphere packaging with cellophane	3 days	4 °C	Best for storage	(51)
14.	Roses 'Avalanche'	Controlled atmosphere (3 % O2 and 6 % CO2)	14 days and 21 days	1 °C	Significantly higher lower quality, longer green foliage and minor *Botrytis cinerea* incidence	(52)
15.	Tulip	Modified atmosphere packaging	20days	0 °C	Significantly better and successfully extended postharvest life	(53)

Modern Storage and Cold Chain Management

Maintaining a robust and uninterrupted cold chain is fundamental to preserving the quality and extending the vase life of cut flowers intended for export, particularly those shipped by air to distant markets (54). The cold chain begins immediately after harvest with rapid field heat removal often through vacuum or forced-air pre-cooling and continues through refrigerated storage at grading and packaging centres (55). From there, flowers are transported in temperature-controlled trucks and stored in chilled air cargo holds to ensure consistent low temperatures throughout the journey(56). Any break in this cold chain can lead to accelerated respiration, moisture loss, microbial growth and ultimately, reduced marketability (57). To enhance preservation during longer storage periods, advanced storage methods such as Controlled Atmosphere (CA) and Modified Atmosphere (MA) storage are employed. These systems carefully regulate levels of oxygen (O_2), carbon dioxide (CO_2) and relative humidity (RH) to suppress senescence, microbial proliferation and ethylene activity (58). Storage is commonly used in centralized distribution hubs and flower auctions such as the world-renowned Aalsmeer Flower Auction in the Netherlands, where it helps maintain the freshness of bulk flower stocks awaiting sale (13). Technological advancements have further bolstered cold chain management through the use of real-time monitoring tools (59). Temperature loggers, IoT-based sensors and GPS tracking devices provide continuous feedback on environmental conditions and shipment location, enabling stakeholders to detect and resolve transit delays, equipment failures or temperature excursions before they compromise flower quality (60). Real-world case studies underscore the effectiveness of these systems: in Kenya, the integration of vacuum cooling and centralized cold storage facilities at Jomo Kenyatta International Airport (JKIA) has reduced postharvest losses by more than 20 %, enhancing the reliability of exports to European markets (61). Similarly, Colombia's cold chain logistics spanning from farm to Miami allow flowers to reach the U.S. market within 48 to 72 hours of harvest, preserving visual appeal and freshness (62). These examples highlight how investments in cold chain infrastructure and smart logistics are pivotal to sustaining quality standards and ensuring competitiveness in the global floriculture trade.

Consumer Expectations and Quality Perception

Consumer expectations play a vital role in shaping the standards and practices of the global cut flower industry, with quality perception beginning at the point of purchase and continuing through the vase life experience (63). Buyers typically assess flower freshness and appeal based on visible and sensory attributes such as bud tightness, color vibrancy, leaf greenness and the absence of bruises, wilting or signs of dehydration (64). For fragrant species, the presence of a natural, balanced scent is desirable strong enough to enhance the sensory appeal but not overwhelming as seen in flowers such as *Rosa hybrida* (roses), *Jasminum sambac* (jasmine) and *Lavandula angustifolia* (lavender) (65). In premium markets, these expectations extend beyond the physical product to include branding and packaging aesthetics (66). High-end packaging not only protects flowers but also enhances the unboxing experience with recyclable or artistically designed materials, custom branding and informational inserts that share flower care tips or origin stories. For instance, a package might highlight that the blooms were cultivated "at 2,000 meters in the Ecuadorian Andes" (67). Such narratives add emotional value and foster consumer loyalty. Additionally, the integration of digital feedback mechanisms has enabled producers to stay closely attuned to consumer preferences (68). Online platforms and retailer data collection tools allow floriculture businesses to receive real-time insights into how flowers are performing in-market (69). This feedback helps growers fine-tune harvest timing to match consumer demand for bud openness or coloration, select floral varieties with improved postharvest performance and revise packaging or hydration protocols to improve shelf life. Increasingly, retailer-buyer feedback loops are becoming essential components of quality assurance programs and are also guiding research and development strategies (70). By aligning production with market feedback, exporters can better meet consumer expectations, reduce product waste and strengthen their position in competitive international markets.

Future Perspectives and Research Gaps

The future of postharvest handling in the cut flower industry lies at the intersection of technology, sustainability and inclusive development, with significant potential for innovation and improvement across the value chain (71). Emerging smart technologies, such as artificial intelligence (AI), are being explored for their capacity to predict vase life and detect early signs of quality degradation, thereby enabling more precise quality control and shelf-life estimation for example, AI-driven image analysis systems that assess petal discoloration or wilting patterns in real time (72). Lock chain systems offer the promise of transparent, tamper-proof supply chains, allowing buyers and consumers to trace the origin and journey of flowers from farm to market, thereby enhancing trust and accountability (72). Similarly, the Internet of Things (IoT) is revolutionizing cold chain logistics through real-time monitoring of temperature, humidity and location, providing critical alerts to pre-empt spoilage or loss during transit (73, 74). In parallel, there is a growing emphasis on sustainability and the inclusion of smallholder farmers, who form the backbone of flower production in many developing nations (75). Innovations such as solar-powered cold storage units for remote farms, affordable biodegradable packaging solutions and the use of indigenous plant extracts for eco-friendly bio preservation not only reduce environmental impact but also make advanced postharvest techniques accessible to marginalized producers (76). Despite these advances, several research gaps persist. There is a paucity of comprehensive data on the physiological responses of different flower species under stress conditions such as fluctuating temperatures or low humidity information vital for optimizing handling protocols (77). Furthermore, the development of disease-resistant cultivars tailored for export markets remains limited, highlighting the need for targeted breeding programs (78). Another critical gap lies in the life-cycle assessment (LCA) of postharvest practices and materials, which is essential for understanding the environmental footprint of packaging, preservatives and logistics operations (79). Addressing these research gaps, while integrating digital and sustainable innovations, will be key to building a resilient, equitable and environmentally responsible future for the global cut flower trade.

Conclusion

Recent innovations in postharvest handling have significantly transformed the global cut flower industry, making it more resilient, efficient and environmentally conscious. Advances in vase life extension, microbial control, automated grading and sustainable packaging have greatly improved flower quality during export. Yet, challenges remain in infrastructure, sustainability and smallholder participation. To meet evolving global standards and consumer preferences, the industry must adopt an integrated and collaborative approach involving research institutions, governments, logistics providers and producers. Emphasis on innovation, sustainability and inclusive policies will ensure that the benefits of a robust floriculture value chain are widely distributed, environmentally responsible and future-ready.

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Authors' contributions

SA prepared the entire manuscript. SSV and SAR provided technical guidance in structuring the manuscript and approved the final version. KG, DA, PT and RJ also contributed by guiding the manuscript preparation and approving the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

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References

1. Devrani N, Kakkar P, Sahu A, Tiwari C. Global trends in floriculture. Floric Landscaping Chron Revital Floric Sect Sri Lanka Collab Insights. 2023;190–221.
2. Anumala NV, Kumar R. Floriculture sector in India: Current status and export potential. J Hortic Sci Biotechnol. 2021;96(5):673–80. https://doi.org/10.1080/14620316.2021.1902863
3. Jhanji S, Kaur G, Chumber M. Deciphering flower senescence physiology: Advancements in post-harvest storage and preservation techniques for enhancing longevity. J Hortic Sci Biotechnol. 2025;100(2):164–95. https://doi.org/10.1080/14620316.2024.2404039
4. Al-Dairi M, Pathare PB, Al-Yahyai R, Opara UL. Mechanical damage of fresh produce in postharvest transportation: Current status and future prospects. Trends Food Sci Technol. 2022;124:195–207. https://doi.org/10.1016/j.tifs.2022.04.018
5. Duan Z, Liu W, Zeng S, Zhu C, Chen L, Cui W. Research on a real-time, high-precision end-to-end sorting system for fresh-cut flowers. Agriculture. 2024;14(9):1532. https://doi.org/10.3390/agriculture14091532
6. El-Ramady HR. Integrated nutrient management and postharvest of crops. Sustain Agric Rev. 2013;13:163–274. https://doi.org/10.1007/978-3-319-00915-5_8
7. Brahma BJ, Antil RS, Yadav SK, Kaushik N. A study on the effect of silver nitrate and 8-hydroxyquinoline citrate pulsing solutions on Lilium cut flowers. J Appl Nat Sci. 2023;15(2). https://doi.org/10.31018/jans.v15i2.4608
8. Kumar N, Srivastava GC, Dixit K. Flower bud opening and senescence in roses (*Rosa hybrida* L.). Plant Growth Regul. 2008;55:81–99. https://doi.org/10.1007/s10725-008-9263-x
9. Sharma S, Thakur AK, Maiti R. Post-harvest technology for reducing stress on bioresource: Recent advances and future needs. Bioresour Stress Manag. 2016;229–56. https://doi.org/10.1007/978-981-10-0995-2_12
10. Veen H. Silver thiosulphate: An experimental tool in plant science. Sci Hortic. 1983;20(3):211–24. https://doi.org/10.1016/0304-4238(83)90001-8
11. Davies PJ. The plant hormones: their nature, occurrence and functions. In: Plant hormones: physiology, biochemistry and molecular biology. Springer; 1995. p. 1–12. https://doi.org/10.1007/978-94-011-0473-9_1
12. Paul V, Pandey R. 1-Methylcyclopropene (1-MCP) treatments. In: Novel postharvest treatments of fresh produce. CRC Press; 2017. p. 149–216. https://doi.org/10.1201/9781315370149-7
13. Hooker MT. The history of Holland. Bloomsbury Publishing USA; 1999. https://doi.org/10.5040/9798400664847
14. Chen L, Wang M, Wang H, Zhou C, Yuan J, Li X, et al. Isothermal storage delays the senescence of post-harvest apple fruit through the regulation of antioxidant activity and energy metabolism. Foods. 2023;12(9):1765. https://doi.org/10.3390/foods12091765
15. Hatibarua P, Talukdar MC, Mahanta S, Sarmah R, Deka K, Das J. Effect of different wet packaging methods on flower quality of Anthurium for long distance transportation. Pharma Innov J. 2022;11:1785–7.
16. Dhiman MR, Kumar R, Kumar S. Postharvest handling and disease management of cut flowers. In: Postharvest handling and diseases of horticultural produce. CRC Press; 2021. p. 415–30. https://doi.org/10.1201/9781003045502-35
17. Erbs G, Newman MA. Plant diseases caused by prokaryotes: Bacteria and mollicutes. In: Agrios' plant pathology. Elsevier; 2024. p. 465–546. https://doi.org/10.1016/b978-0-12-822429-8.00016-9
18. Vijay Rakesh Reddy S, Sudhakar Rao DV, Sharma RR, Preethi P, Pandiselvam R. Role of ozone in post-harvest disinfection and processing of horticultural crops: A review. Ozone Sci Eng. 2022;44(1):127–46. https://doi.org/10.1080/01919512.2021.1994367
19. Gąstoł M, Błaszczyk U. Effect of magnetic field and UV-C radiation on postharvest fruit properties. Agriculture. 2024;14(7):1167. https://doi.org/10.3390/agriculture14071167
20. Xu Y, Bassi A. Non-thermal plasma decontamination of microbes: A state of the art. Biotechnol Prog. 2025;41(2):e3511. https://doi.org/10.1002/btpr.3511
21. Sun X, Baldwin E, Bai J. Applications of gaseous chlorine dioxide on postharvest handling and storage of fruits and vegetables – A review. Food Control. 2019;95:18–26. https://doi.org/10.1016/j.foodcont.2018.07.044
22. Tanasă F, Nechifor M, Teacă CA. Essential oils as alternative green broad-spectrum biocides. Plants. 2024;13(23):3442. https://doi.org/10.3390/plants13233442
23. Marshall D. Sanitation, sterilization and disinfection. Mosbys Compr Rev Vet Tech E-Book. 2024;222.
24. Sosnowski MR, Fletcher JD, Daly AM, Rodoni BC, Viljanen-Rollinson SLH. Techniques for the treatment, removal and disposal of host material during programmes for plant pathogen eradication. Plant Pathol. 2009;58(4):621–35. https://doi.org/10.1111/j.1365-3059.2009.02042.x
25. Lalam R, Lavanya K, Nadella V, Kiran BR. Automatic sorting and grading of fruits based on maturity and size using machine vision and artificial intelligence. J Sci Res Rep. 2025;31(1):153–63. https://doi.org/10.9734/jsrr/2025/v31i12754
26. Soleimanipour A, Chegini GR. A vision-based hybrid approach for identification of Anthurium flower cultivars. Comput Electron Agric. 2020;174:105460. https://doi.org/10.1016/j.compag.2020.105460
27. Xu Z, Jiang D. AI-powered plant science: transforming forestry monitoring, disease prediction and climate adaptation. Plants. 2025;14(11):1626. https://doi.org/10.3390/plants14111626
28. Jin T, Han X. Robotic arms in precision agriculture: A comprehensive review of the technologies, applications, challenges and future prospects. Comput Electron Agric. 2024;221:108938. https://doi.org/10.1016/j.compag.2024.108938
29. Liberty JT, Habnabakize E, Adamu PI, Bata SM. Advancing food manufacturing: Leveraging robotic solutions for enhanced quality assurance and traceability across global supply networks. Trends Food Sci Technol. 2024;104705. https://doi.org/10.1016/j.tifs.2024.104705
30. van Liemt G. The world cut flower industry: Trends and prospects. International Labour Office; 1999.
31. Cheng K. Sustainable packaging approaches for current waste challenges. Massachusetts Institute of Technology; 2019.
32. Samanta KK, Basak S, Chattopadhyay SK. Potentials of fibrous and nonfibrous materials in biodegradable packaging. Environ Footpr Packag. 2016;75–113. https://doi.org/10.1007/978-981-287-913-4_4
33. Wani MA, Din A, Nazki IT, Rehman TU, Al-Khayri JM, Jain SM, et al. Navigating the future: Exploring technological advancements and emerging trends in the sustainable ornamental industry. Front Environ Sci. 2023;11:1188643. https://doi.org/10.3389/fenvs.2023.1188643
34. Ghoshal G. Recent trends in active, smart and intelligent packaging for food products. In: Food packaging and preservation. Elsevier; 2018. p. 343–74. https://doi.org/10.1016/b978-0-12-811516-9.00010-5
35. Álvarez-Hernández MH, Martínez-Hernández GB, Avalos-Belmontes F, Castillo-Campohermoso MA, Contreras-Esquivel JC, Artés-Hernández F. Potassium permanganate-based ethylene scavengers for fresh horticultural produce as an active packaging. Food Eng Rev. 2019;11:159–83. https://doi.org/10.1007/s12393-019-09193-0
36. George J, Kumar R, Aaliya B, Sunooj KV. Packaging solutions for

monitoring food quality and safety. In: Engineering aspects of food quality and safety. Springer; 2023. p. 411–42. https://doi.org/10.1007/978-3-031-30683-9_14

37. Neumann T. Comparative analysis of long-distance transportation with the example of sea and rail transport. Energies. 2021;14 (6):1689. https://doi.org/10.3390/en14061689

38. Tiamiyu NAT. Exploring next generation packaging systems in a refrigerated container using CFD modelling. Stellenbosch: Stellenbosch University; 2020.

39. Dauda WP, Dantata IJ, Adetunji CO, Abraham P, Ifeanyi UJ, Glen E, et al. The effect of evaporative coolant structure on ornamental plants. In: Evaporative coolers for the postharvest management of fruits and vegetables. Elsevier; 2023. p. 209–35. https://doi.org/10.1016/B978-0-323-89864-5.00011-4

40. Fadda A, Palma A, Azara E, D'Aquino S. Effect of modified atmosphere packaging on overall appearance and nutraceutical quality of pot marigold held at 5 °C. Food Res Int. 2020;134:109248. https://doi.org/10.1016/j.foodres.2020.109248

41. Kou L, Turner ER, Luo Y. Extending the shelf life of edible flowers with controlled release of 1-methylcyclopropene and modified atmosphere packaging. J Food Sci. 2012;77(5):S188–93. https://doi.org/10.1111/j.1750-3841.2012.02683.x

42. Burana C, Kurokura T, Yamaki Y, Yamane K. Modified atmosphere (MA) and 1-methylcyclopropene (1-MCP) combination treatment extends the postharvest life of carnations. Environ Control Biol. 2014;52(3):131–6. https://doi.org/10.2525/ecb.52.131

43. Zeltzer S, Meir S, Mayak S. Modified atmosphere packaging (MAP) for long-term shipment of cut flowers. In: IV International Conference on Postharvest Science 553. 2000. p. 631–4. https://doi.org/10.17660/ActaHortic.2001.553.152

44. Poonsri W. Effects of active and passive modified atmosphere packaging on biochemical properties of cut Dendrobium orchid flowers. Heliyon. 2021;7(6). https://doi.org/10.1016/j.heliyon.2021.e07197

45. Poonsri W. Effect of modified and controlled atmosphere storage on enzyme activity and senescence of Dendrobium orchids. Heliyon. 2020;6(9). https://doi.org/10.1016/j.heliyon.2020.e05070

46. Patel T, Singh A. Effect of different modified atmosphere packaging (MAP) films and cold storage temperatures (5, 10 and 15 °C) on keeping quality of gerbera (*Gerbera jamesonii*) flowers. In: IX International Symposium on Postharvest Quality of Ornamental Plants 847. 2008. p. 353–8. https://doi.org/10.17660/ActaHortic.2009.847.48

47. Ali SM, Nidoni U, Palanimuthu SH, Ramappa K, Ramesh G, Naik N. Enhancing shelf life and freshness retention in jasmine flowers (*Jasminum multiflorum* L.) through post-harvest chemical treatments. Int J Adv Biochem Res. 2024;8:265–70. https://doi.org/10.33545/26174693.2024.v8.i3Sd.720

48. Chrysargyris A, Tzionis A, Xylia P, Tzortzakis N. Effects of salinity on Tagetes growth, physiology and shelf life of edible flowers stored in passive modified atmosphere packaging or treated with ethanol. Front Plant Sci. 2018;9:1765. https://doi.org/10.3389/fpls.2018.01765

49. Pal S, Kumar Ghosh P, Bhattacharjee P. Effect of packaging on shelf -life and lutein content of marigold (*Tagetes erecta* L.) flowers. Recent Pat Biotechnol. 2016;10(1):103–20. https://doi.org/10.2174/1872208310666160725195516

50. Yahia EM, Singh SP. Tropical fruits. In: Modified and controlled atmospheres for the storage, transportation and packaging of horticultural commodities. CRC Press; 2009. p. 415–62. https://doi.org/10.1201/9781420069587-20

51. Dastagiri D, Sharma BP, Dilta BS. Effect of wrapping materials and cold storage durations on keeping quality of cut flowers of *Ornithogalum thyrsoides* Jacq. Indian J Appl Res. 2014;4(2):4–6. https://doi.org/10.15373/2249555X/FEB2014/71

52. Díaz JMS, Jiménez-Becker S, Jamilena M. A screening test for the determination of cut flower longevity and ethylene sensitivity of carnation. Hortic Sci. 2017;44(1):153. https://doi.org/10.17221/134/2015-HORTSCI

53. Aros D, Orellana K, Escalona V. Modified atmosphere packaging as a method to extend postharvest life of tulip flowers. N Z J Crop Hortic Sci. 2017;45(3):202–15. https://doi.org/10.1080/01140671.2017.1296872

54. Faust JE, Dole JM. Cut flowers and foliages. CABI; 2021. https://doi.org/10.1079/9781789247602.0000

55. Desai YG, Bhujel S, Bharadwaj RMM. Fruit Science Chronicles: A Collaborative Insight. Vol. 1. 1st ed. Stella International Publication; 2024. 178 p.

56. Behdani B, Fan Y, Bloemhof JM. Cool chain and temperature-controlled transport: An overview of concepts, challenges and technologies. Sustain Food Supply Chains. 2019;167–83. https://doi.org/10.1016/b978-0-12-813411-5.00012-0

57. Kitinoja L. Use of cold chains for reducing food losses in developing countries. Population. 2013;6(1.23):5–60.

58. Kubo Y. Ethylene, oxygen, carbon dioxide and temperature in postharvest physiology. In: Abiotic stress biology in horticultural plants. Springer; 2014. p. 17–33. https://doi.org/10.1007/978-4-431-55251-2_2

59. Mustafa MFMS, Namasivayam N, Demirovic A. Food cold chain logistics and management: A review of current development and emerging trends. J Agric Food Res. 2024;101343. https://doi.org/10.1016/j.jafr.2024.101343

60. Selvam AP, Al-Humairi SNS. The impact of IoT and sensor integration on real-time weather monitoring systems: A systematic review. 2023. https://doi.org/10.21203/rs.3.rs-3579172/v1

61. Karithi EM. Evaluation of the efficacy of CoolBot™ cold storage technology to preserve quality and extend shelf life of mango fruits. University of Nairobi; 2016.

62. Siegler J. How Miami became the gateway for flowers in the USA. Int J Teach Case Stud. 2020;11(3):208–22. https://doi.org/10.1504/IJTCS.2020.111136

63. de Keijzer ROB. A new journey from flower to vase. 2024.

64. Kelley KM. Environmental constraints on marketing, production and postharvest shelf life of edible flowers. Michigan State University; 2000.

65. Spence C. Using ambient scent to enhance well-being in the multisensory built environment. Front Psychol. 2020;11:598859. https://doi.org/10.3389/fpsyg.2020.598859

66. Simonson A, Schmitt BH. Marketing aesthetics: The strategic management of brands, identity and image. Simon and Schuster; 1997.

67. Barbero S. Packaging design in the digital age: a systemic approach to e-commerce. 2020.

68. Rayna T, Striukova L. Involving consumers: The role of digital technologies in promoting 'prosumption' and user innovation. J Knowl Econ. 2021;12:218–37. https://doi.org/10.1007/s13132-016-0390-8

69. Nyamete LK. Supply chain resilience strategies and performance of floricultural firms in Nakuru county, Kenya. 2024.

70. Parker-Strak R, Boardman R, Barnes L, Doyle S, Studd R. Product development, fashion buying and merchandising. Text Prog. 2022;54(4):247–403. https://doi.org/10.1080/00405167.2023.2182062

71. Kaur R, Watson JA. A scoping review of postharvest losses, supply chain management and technology: implications for produce quality in developing countries. J ASABE. 2024;67(5):1103–31. https://doi.org/10.13031/ja.15660

72. Bandara K, Katukurunda K. Exploring the Blockchain's Green

Revolution in Medicinal Plant Supply Chains (Blossoming Trust)–A Review. J Agric Value Addit. 2024;7(2). https://doi.org/10.4038/java.v7i2.137

73. Cil AY, Abdurahman D, Cil I. Internet of Things enabled real time cold chain monitoring in a container port. J Shipp Trade. 2022;7(1):9. https://doi.org/10.1186/s41072-022-00110-z
74. Pajic V, Andrejic M, Chatterjee P. Enhancing cold chain logistics: A framework for advanced temperature monitoring in transportation and storage. Mechatron Intell Transp Syst. 2024;3(1):16–30. https://doi.org/10.56578/mits030102
75. Mebrat S, Degwale A, Mekonen T, Mebrat A. Flower production prospects and sustainability challenges in Ethiopia: A systematic review. Front Environ Sci. 2022;10:1026544. https://doi.org/10.3389/fenvs.2022.1026544
76. Garcia E de S, Quaresma N, Aemro YB, Coimbra AP, De Almeida AT. Cooling with the sun: Empowering off-grid communities in developing countries with solar-powered cold storage systems. Energy Res Soc Sci. 2024;117:103686. https://doi.org/10.1016/j.erss.2024.103686
77. Proietti S, Scariot V, De Pascale S, Paradiso R. Flowering mechanisms and environmental stimuli for flower transition: Bases for production scheduling in greenhouse floriculture. Plants. 2022;11(3):432. https://doi.org/10.3390/plants11030432
78. Nelson R, Wiesner-Hanks T, Wisser R, Balint-Kurti P. Navigating complexity to breed disease-resistant crops. Nat Rev Genet. 2018;19(1):21–33. https://doi.org/10.1038/nrg.2017.82
79. Lan YC, Tam VW, Xing W, Datt R, Chan Z. Life cycle environmental impacts of cut flowers: A review. J Clean Prod. 2022;369:133415. https://doi.org/10.1016/j.jclepro.2022.133415

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