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Shelf life optimization of flower crops and ornamentals: A comprehensive review of post-harvest treatments

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Abstract

In the global floral industry, cut flowers are an essential part that greatly enhances both looks and economic worth. However, prolonging the shelf life of flowers, particularly after their harvesting, is one of the main issues facing the floral enterprise. In order to solve this issue, several kinds of post-harvest treatments have been studied. With an emphasis on the mechanisms of action, efficacy, and possible advantages of these treatments, this review paper aims to present an in-depth study of the many chemical and preservative technologies used to enhance the shelf life of flowers. By reviewing the current research, this paper will highlight how post-harvest interventions can improve flower shelf life, quality, and consumer satisfaction.

Keywords: Optimization, shelf life, post-harvest treatments, ornamental plants

Introduction

The global floriculture sector is essential to agriculture and the economy, providing a substantial contribution to industry, employment, and cultural heritage. The Food and Agriculture Organization (FAO) estimates that the floriculture industry, which includes the production and sale of flowers, potted plants, and ornamental foliage, is a significant agricultural sector with a global market value of more than \$50 billion (FAO, 2020) ^[18]. The industry places a high emphasis on flowers' aesthetic and cultural significance in addition to its usage in interior decorating, landscaping, and events (Nilsen & Pade, 2019) ^[35]. The perishable nature of ornamental plants and cut flowers is one of the main issues facing the floriculture sector. Due to their very short shelf life, these products are not as marketable, especially when it comes to international trade. Both the aesthetic value and economics of these products are affected by the rapid decline in flower quality that occurs after harvest, primarily because of microbial spoilage and wilting (Sampath *et al.*, 2021) ^[47]. The short shelf life of cut flowers and ornamentals, however, is one of the main issues facing the sector and directly affects marketability and profitability. With a market worth billions of dollars, it is a sizable agricultural industry that produces and sells flowers, potted plants, and decorative foliage. In the world, the large producers like Kenya, Ecuador, and Colombia, which benefit from cost-effectiveness and suitable climates, and the Netherlands, which leads in exports thanks to its sophisticated auction and logistics systems (Chandrappa & Das, 2021; Kumar & Kumar, 2020) ^[12, 27]. Although North America and Europe continue to be the main markets, growing demand in Asia due to e-commerce and

development indicates a change in customer preferences (Kumar & Kumar, 2020) ^[27]. With women contributing up to a significant proportion of the workforce, the sector sustains millions of employment, especially in developing nations (Muriithi *et al.*, 2021) ^[33]. Nevertheless, issues that include resource-intensive operations, supply chain interruptions, and environmental sustainability—all of which have been made worse by the COVID-19 pandemic—call for adaptable approaches (Bhattacharjee & De, 2005a; Singh *et al.*, 2021) ^[7, 8, 55]. For the industry to be resilient and sustainable, innovations in smart greenhouses, precision agriculture, and certifications that support ethical production are essential (Chandrappa & Das, 2021; Singh *et al.*, 2021) ^[12, 55].

India's varied agro-climatic conditions and rising demand for both traditional and modern flowers have contributed to fast growth of floriculture industries as a sector of the agricultural economy. Karnataka, Tamil Nadu, Maharashtra, and West Bengal are among the major flower-producing states that specialize in cut flowers like roses, carnation, chrysanthemum and gerberas for commercial usage and loose flowers like marigold and jasmine for cultural use (Chandrappa & Das, 2021; Kumar & Kumar, 2020) ^[12, 27]. Driven by government programs like the National Horticulture Mission, which encourages modern farming and post-harvest procedures, export, have increased, with important markets including the Netherlands, the United States, and Japan (NHB, 2021) ^[34]. Innovation like precision farming, greenhouse technology, and pre- and post-harvest chemical treatments are bridging the gap despite challenges including fragmented production, inadequate storage, and environmental issues brought on by water-intensive and pesticide-reliant farming. Furthermore, Indian floriculture

now has new prospects and is positioned as a significant economic contributor since the growth of e-commerce platforms and sustainable practices (Singh *et al.*, 2021) ^[55]. Effective pre- and post-harvest treatments can significantly improve the storage, transportation, and retail value of flowers (Boonplod *et al.*, 2021) ^[9]. This review examines the different chemical treatments, preservatives, and their mechanisms to optimize the shelf life and overall quality of cut flowers.

Optimizing shelf life combines post-harvest management strategies with pre-harvest considerations, such as cultivar selection. In order to reduce environmental and physiological stressors that lead to senescence, include, as ethylene-induced wilting, microbial contamination, and water loss, post-harvest treatments are essential. By preserving the ideal gas compositions surrounding flowers in storage, advanced methods such as modified atmosphere (MA) and controlled atmosphere (CA) storage have been demonstrated to be successful in increasing shelf life (Singh *et al.*, 2009) ^[56]. For example, MA storage prolongs the freshness of cut flowers such as chrysanthemums and roses by improving water balance and lowering respiration rates (Janick, 2011; Mortensen & Moe, 1992) ^[24, 32]. Chemical methods help flowers meet their individual physiological needs, as an additional benefit to these processes. It has been demonstrated that pulsing using solutions containing citric acid, sugar, and antibacterial agents can maintain flower turgidity and delayed senescence process. By inhibiting microbial development and maintaining cellular turgidity, a mixture of 7% sucrose, 0.5% citric acid, and 0.5% aluminum sulfate successfully increased the shelf life of roses (Jadhav *et al.*, 2018) ^[22]. Furthermore, post-harvest performance is improving by methods like pulsing solution with floral preservatives and storage in controlled conditions, especially for lilies and gerbera (Singh *et al.*, 2007) ^[53].

Post-harvest management, packaging innovations are equally important. Packaging materials like polypropylene, cellophane, and biodegradable alternatives provide mechanical protection, reduce moisture loss, and facilitate modified atmosphere conditions during transportation (Patil & Singh, 2009) ^[39]. Proper packaging also minimizes mechanical damage, becoming a major concern during long-distance commerce, and supports sustainable practices. Harvesting flowers at their ideal maturity stage is another important factor influencing post-harvest life of flowers and ornamental plants. Flowers are harvested at the right maturity stage possess more vase life and overall quality example, daisy-type flowers are harvested at full bloom, while spike flowers, like gladiolus, are collected when one-fourth to half of the florets are open (Bhattacharjee & De, 2003) ^[5]. According to Nowak and Rudnicki (1990) ^[36], water uptake and resistance to post-harvest stresses are influenced by the harvesting method and right time. Researching and strengthening post-harvest technology becomes essential given the increasing demand for floriculture products. This paper offers a thorough examination of the methods used to extend the shelf life of ornamentals and flower crops, emphasizing their practicality, sustainability, and effectiveness. By connecting the gap between industry practices and scientific advances, the findings prefer to support the floriculture sector's

resilience and expansion.

Factors affecting post-harvest of flower and ornamental crops

Handling, physiological, and environmental factors all affect the postharvest shelf life of flowers and ornamental plants. Although treatments like 1-MCP decrease these effects, higher respiration rates increase senescence and the breakdown of carbohydrates, whereas ethylene accelerates aging (Halevy & Mayak, 1981; Reid & Jiang, 2012) ^[21, 45]. Because xylem blockages can decrease turgidity, that can be enhanced by stem re-cut and by antimicrobial treatments, proper water relations are essential (Dole & Wilkins, 2005; Reid & Jiang, 2012) ^[16, 15, 45]. Although controlling temperature slows metabolism, tropical species must reduce chilling injuries in ornamental plants (Van Doorn & Woltering, 2008; Bhattacharjee & De, 2005b) ^[61, 7, 8]. High humidity prevents loss of moisture and controlled to prevent the growth of fungi (Nowak & Rudnicki, 1990) ^[36]. Damage and infection risk are reduced by appropriate handling and packing (Bhattacharjee & De, 2005b) ^[7, 8]. Senescence can be delayed by chemical treatment options such as ethylene inhibitors and sucrose solutions, particularly in susceptible species (Reid & Jiang, 2012; Halevy & Mayak, 1981) ^[45, 21]. Longevity is additionally affected by storage conditions, temperature order and genetic variability; because of inherent characteristics, species such as orchids and anthuriums endure roses and tulips (Van Doorn & Woltering, 2008; Nowak & Rudnicki, 1990) ^[61, 36].

Postharvest treatments to increase shelf life of flowers and ornamental plants

Flowers and ornamental plants can have increased shelf life by a number of postharvest chemical treatments that maintain quality, delay senescence, and prevent spoiling of flowers. Citrus acid based treatments improve water absorption by lowering pH and preventing vascular blockage (Dole & Wilkins, 2005) ^[15]. According to Reid and Jiang (2012) ^[45], preservative solutions that contain sugars, biocides, and acidifiers promote longevity by supplying energy, regulating microbial growth, and improving water conductivity. For ethylene-sensitive species, several ethylene inhibitors such as 1-MCP and silver thiosulfate (STS) are essential because they delay the senescence of flowers like orchids, carnations, and roses (Halevy & Mayak, 1981; Veen *et al.*, 2022) ^[21, 62]. While tropical flowers need greater temperatures to avoid chilling injuries, cooling and maintaining an ideal cold chain (0-5°C for most flowers) slows respiration and ethylene production (Nowak & Rudnicki, 1990) ^[36]. Despite high humidity (90-95%) reduces water loss, it prevents the growth of fungi (Bhattacharjee & De, 2005) ^[7, 8]. By enhancing water absorption, chemical preservatives such as silver thiosulfate prolong vase life, especially in tulips and lilies. According to Dole and Wilkins (2005) ^[15], pulsing treatments with sucrose, calcium, or gibberellins delay aging by strengthening cell walls and providing nutrients. By suppressing microbial development, antimicrobial compounds such as silver nitrate and chlorine dioxide keep xylem arteries open (Reid & Jiang, 2012) ^[45]. Modified atmosphere packaging (MAP) along with additional packaging techniques delaying respiration and ethylene

generation by increasing carbon dioxide and decreasing oxygen (Van Doorn & Woltering, 2008) ^[61]. While biotechnological methods such as genetically modifying a person to become less sensitive to ethylene provide new solutions, UV-C irradiation inhibits microbial development and creates stress tolerance (Reid & Jiang, 2012; Van Doorn & Woltering, 2008) ^[45, 61]. Post-harvest solutions are containing water, carbohydrates, and antimicrobial agents increase shelf life, control microbial, and hydration (Wu *et al.*, 2018; McCarter *et al.*, 2021; Chen *et al.*, 2019a & 2019b) ^[64, 13, 14, 30].

Mechanisms of action of post-harvest treatments: The effectiveness of post-harvest treatments can attribute to several physiological and biochemical mechanisms. These include:

- **Water retention:** Post harvest chemical treatments, containing sugars and calcium help retain water within the flowers, preventing wilting and water loss of flowers (Ravichandran *et al.*, 2021) ^[41].
- **Microbial control:** Preservatives and antimicrobial agents like silver ions or antibiotics decrease microbial growth in vase solutions, which can cause blockages in the flower's vascular system (Jung *et al.*, 2020) ^[26].
- **Ethylene inhibition:** Anti-ethylene treatments block the harmful effects of ethylene that accelerates the aging of flowers, resulting in longer shelf life of flowers (Shang *et al.*, 2023) ^[50].
- **Cell wall strengthening:** Some post-harvest chemical treatments enhance the structural turgidity of flower tissues, making them more resilient to physical damage and slow down senescence (Liu *et al.*, 2021) ^[29].

Challenges and Limitations of Post-Harvest Treatments

1. **Physiological and Structural Variability:** The physiological and structural traits of flowers and ornamental plants vary widely, which makes it difficult to develop post-harvest treatments that are successful for all. Species and cultivars differ greatly in their susceptibility to ethylene, water stress, and microbial diseases (Reid & Jiang, 2012) ^[45].
2. **Ethylene Sensitivity and Control:** The plant's hormone ethylene causes senescence to accelerate in many flowers. While the efficacy of inhibitors such as silver thiosulfate (STS), regulatory limitations and environmental concerns limit their use (Van Doorn, 2017) ^[59]. Alternative substances, like 1-MCP, have potential but need to use appropriately.
3. **Microbial Contamination:** The growth of microorganisms in vase water or on plant surfaces can cause vascular system that lead lowers water absorption. Some chemical preservatives are control microbiological contamination in vase solutions, but customers and regulators are resistant to them because of toxicity concerns (Gaurav *et al.*, 2020a and Gaurav *et al.*, 2020b) ^[20].
4. **Cold Chain and Storage Infrastructure:** Maintaining a consistent cold chain is critical but resource-intensive. Developing countries face challenges with lack of cold store infrastructure that lead to post harvest losses despite the use of chemical treatments decrease the losses (Prasad *et al.*, 2021) ^[40].

5. **Consumer Preferences and Safety Concerns:** There is increasing demand for flowers treated with safe, eco-friendly solutions. However, many bio-based treatments, such as plant extracts or essential oils, are less effective than synthetic chemicals in extending vase life, limiting their widespread adoption (Dole *et al.*, 2018) ^[16].
6. **Cost and Feasibility:** New technologies, such as nanotechnology-based treatments or biopolymer coatings, can significantly increase shelf life of flowers but are expensive and not accessible to small-scale growers (Bhat *et al.*, 2021) ^[4].
7. **Regulatory and Environmental Concerns:** The use of chemicals like STS, silver nitrate is increase regulated due to their environmental impact. The search for alternatives that balance efficacy and sustainability remains a major challenge (Jones *et al.*, 2019) ^[25].

Emerging trends and Alternatives in post-harvest management of flower crops

Post-harvest management of flower crops has seen significant advancements with the combination of sustainable practices, technological innovations, and alternative treatments. One of the new emerging trends is the use of biodegradable and eco-friendly preservatives. Plant-based treatments such as chitosan-based coatings, plant extracts, and essential oils have gained attention for their antimicrobial properties and ability to extend the vase life of flowers without harmful environmental residues (Gaurav *et al.*, 2020) ^[20]. Nanotechnology also plays a crucial role in improving the post-harvest quality of flowers. Silver nanoparticles (AgNPs) and zinc oxide nanoparticles are used for their high antimicrobial property, while nano-encapsulation methods provide a controlled release of preservatives, enhancing their effectiveness (Moghadam *et al.*, 2021) ^[31]. Moreover, the management of ethylene, a key regulator of flower senescence, has seen advancements in the use of ethylene inhibitors such as 1-methylcyclopropene (1-MCP) and natural plant-based inhibitors. These alternatives offer safer and more sustainable methods to delay senescence compared to traditional chemicals post-harvest treatment methods (Elibox & Umaharan, 2017) ^[17]. Technological innovations, such as the integration of Internet of Things (IoT) systems, are also focus on post-harvest practices. IoT-enabled sensors monitor environmental factors such as temperature and humidity, optimizing conditions during storage and transportation to ensure minimal post-harvest losses (Ansari *et al.*, 2020) ^[2]. In packaging technologies such as Modified Atmosphere Packaging (MAP) and Active Packaging (AP) systems, which regulate gas compositions, are adopt to improve flower preservation by slowing down respiration and microbial growth (Singh *et al.*, 2019) ^[52]. In terms of alternative treatments, natural antioxidants and phytochemical-based solutions are gaining popularity. Natural substances like ascorbic acid and phenolic compounds, derived from plants such as turmeric and neem, help to delay oxidative stress in cut flowers, thereby prolonging their vase life (Parveen *et al.*, 2021; Sharma *et al.*, 2018) ^[38, 62]. Hydrogels, which maintain hydration and release preservatives gradually, are use in flower management to improve the shelf life of cut flowers during

transportation and retail display (Amin & Hosseini, 2022) ^[1]. Moreover, solar-powered cold storage systems are introduced to provide sustainable cooling solutions in resource-limited areas, ensuring that flowers are kept at optimal temperatures throughout the supply chain (Reddy *et al.*, 2021) ^[42]. Overall, these emerging trends and alternatives signify a shift towards more sustainable, efficient, and eco-friendly post-harvest management practices in the floriculture industry.

Research studies

There is a growing body of research on extending the shelf life of flower crops and ornamentals through post-harvest treatments. Several studies have reviewed different methods and technologies to optimize their longevity and quality.

Recent studies have focused on a variety of strategies to optimize the shelf life of flower crops and ornamentals by combining innovative technologies and natural treatments. OptiFreeze's OptiBoost technology, for example, has demonstrated a 50% extension in vase life for cut roses through a vacuum-assisted solution that enhances water uptake (OptiFreeze, 2023) ^[37]. Essential oils like thyme and lavender have been found to improve the vase life of cut flowers due to their antimicrobial properties, with thyme oil at 50 ppm enhancing water uptake and maintaining fresh weight in roses and gerbera (Sardoei *et al.*, 2024) ^[48]. In addition, chemical treatments, such as sucrose, citric acid, and aluminum sulfate, have been shown to delay petal drop and head-bending in cut roses, with cold storage further extending the storage life (Jadhav *et al.*, 2018) ^[22]. Other studies have highlighted the role of pre-treatment substances like 8-hydroxyquinoline (8-HQ) and nanosilver in reducing enzymatic activity and preserving flower longevity under low oxygen storage (Sun *et al.*, 2022) ^[58]. Additionally, soluble sugars such as sucrose, glucose, and fructose play a significant role in extending vase life by improving water uptake and inhibiting ethylene production (Van Doorn & van Meeteren, 2022) ^[60]. Temperature management is crucial for maintaining flower quality; studies show that optimal storage temperatures help reduce water loss and stress, contributing to longer vase life (Wang *et al.*, 2023) ^[63]. Genetic breeding efforts have also targeted traits like ethylene sensitivity and stomata density to improve vase life in cultivars like *Alstroemeria* and roses (Reid & Jiang, 2023) ^[46]. Packaging technologies like modified atmosphere packaging (MAP) and vacuum packaging have shown promise in extending flower freshness by reducing oxygen exposure and maintaining humidity levels (Singh *et al.*, 2009; Schulz *et al.*, 2023) ^[56, 49]. Environmental factors, such as humidity control and harvest timing, also affect postharvest quality, with high humidity promoting photosynthesis but increasing fungal risk, while proper harvest timing ensures better postharvest performance (Chamani & Wagstaff, 2018; Bhattacharjee & De, 2005) ^[10, 7, 8]. Finally, chemical treatments like methyl jasmonate and silver thiosulfate have been used to block ethylene hormone and fungal infection, thus extending the shelf life of flowers like roses and snapdragons (Reid & Jiang, 2010; Reid, 1998) ^[44, 43]. These findings underscore the importance of integrating multiple strategies, including technological, natural, and chemical approaches, to optimize flower shelf life and quality.

Recent studies have explored the use of nanotechnology to extend the shelf life of flower and ornamental plants, showing promising results in enhancing postharvest quality. One of the most notable applications is the use of silver nanoparticles (AgNPs), which have demonstrated significant potential due to their antimicrobial properties. For instance, Bhat *et al.* (2019) ^[3] and Chandran *et al.* (2021) ^[41] found that AgNPs applied to cut flowers such as roses and chrysanthemums not only inhibited microbial growth but also improved water uptake, thus extending vase life by 35-40%. Similarly, Zhang *et al.* (2020) ^[65] showed that nano-silver coatings applied to gerbera flowers significantly delayed wilting and preserved flower quality by preventing bacterial contamination. Another approach involves nano-clay and nano-capsules, which help control the release of preservatives and nutrients. Singh *et al.* (2022) ^[57] reported that nano-clay-based packaging enhanced water retention and reduced water loss in gerbera flowers, thereby increasing their vase life by up to 50%. Additionally, nano-packaging materials have been developed to release antimicrobial agents, further prolonging flower freshness. Jafari *et al.* (2021) ^[23] reported that the use of nano-encapsulated antimicrobial agents in modified atmosphere packaging (MAP) for roses and tulips resulted in a 30-40% increase in vase life by slowing down metabolic processes and preventing microbial growth. Collectively, these studies highlight the significant role that nanotechnology plays in improving the postharvest longevity of ornamental flowers by reducing microbial activity, enhancing water uptake, and providing controlled-release mechanisms for preservatives. These findings highlight the importance of both postharvest interventions, including genetic improvements and environmental management, in extending the shelf life of ornamental flowers.

Conclusion

To increase the quality and shelf life of cut flowers, post-harvest treatments are essential. As chemical treatments and preservatives have performed well, there is a developing movement toward more environmentally friendly and consumer-friendly approaches. Future advancements in the flower industry are probably going to be driven by ongoing research into creative, non-chemical techniques. Combining plant-based treatments with environment-friendly novel methods to enhance flower longevity and satisfy modern consumer demands.

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