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Postharvest preservation strategies for commercial cut flowers: A comparative review of Chrysanthemum, Tuberose, Gerbera, and Rose

Dr. Manju M George
Associate Professor, Department of Botany, Union Christian College (Autonomous), Aluva, Ernakulam, Kerala, India
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Abstract
Post-harvest deterioration of cut flowers represents a significant economic challenge in the floriculture industry, with vase life extension being critical for commercial viability. This review systematically evaluates and compares post-harvest preservation strategies across four economically important cut flower species—chrysanthemum (*Chrysanthemum morifolium*), tuberose (*Polianthes tuberosa*), gerbera (*Gerbera jamesonii*), and rose (*Rosa hybrida*)—analyzing chemical, physical, and nanotechnology-based interventions. Silver-based compounds (silver thiosulfate, silver nitrate, nano-silver) demonstrated consistent efficacy across all species, with nano-silver particles showing superior antimicrobial activity and vase life extension of 30–60%. Combination treatments integrating carbohydrate sources (2–4% sucrose), antimicrobial agents, and pH modifiers (citric acid, pH 3.5–4.0) consistently outperformed single-component solutions. Species-specific responses were observed: roses showed high ethylene sensitivity requiring anti-ethylene treatments; gerbera exhibited pronounced stem bending addressed by calcium supplementation; chrysanthemum responded favorably to salicylic acid; and tuberose demonstrated unique preservation requirements with limited research coverage. Cold storage (4°C) combined with chemical preservatives extends vase life 3–4 fold compared to ambient conditions. Future research should prioritize species-specific optimization, sustainable bio-based preservatives, and mechanistic understanding of preservation efficacy.

Keywords: Cut flowers, post-harvest preservation, vase life, nano-silver, silver thiosulfate, chrysanthemum, rose, gerbera, tuberose, chemical preservatives

Introduction

The global floriculture industry represents a multi-billion dollar market, with cut flowers constituting a significant economic component valued for ornamental, cultural, and commercial purposes. Post-harvest deterioration poses substantial economic losses, with vase life being a critical quality parameter determining market value and consumer satisfaction. Among commercially important species, chrysanthemum (*Chrysanthemum morifolium*), tuberose (*Polianthes tuberosa*), gerbera (*Gerbera jamesonii*), and rose (*Rosa hybrida*) represent major production volumes globally, each exhibiting distinct physiological characteristics and preservation challenges.

Post-harvest senescence involves complex physiological and biochemical processes including water stress, carbohydrate depletion, ethylene production, microbial proliferation, and membrane deterioration, collectively reducing ornamental quality through petal wilting, discoloration, stem bending, and premature senescence. Extending vase life requires integrated strategies addressing multiple deterioration pathways simultaneously.

Recent advances have introduced diverse preservation approaches ranging from traditional chemical preservatives to innovative nanotechnology-based solutions. Chemical preservatives typically incorporate antimicrobial agents (silver compounds, organic acids), carbohydrate sources (sucrose), anti-ethylene compounds (silver thiosulfate, 1-methylcyclopropene), and plant growth regulators. Nano-silver particles have emerged as promising alternatives offering enhanced antimicrobial efficacy with reduced environmental concerns compared to conventional silver compounds. Despite extensive research on individual preservation methods, comprehensive comparative analyses across multiple species remain limited. This review addresses this gap by systematically analyzing post-harvest preservation strategies across these four commercially significant species, evaluating chemical, physical, and nanotechnology-based interventions, and identifying species-specific requirements and universal principles.

Post-Harvest Physiology and Senescence Mechanisms

1. Water Relations and Hydraulic Conductivity

Water balance represents a fundamental determinant of cut flower longevity, with water uptake capacity and transpiration rate governing turgor maintenance and ornamental quality. Following harvest, cut flowers experience progressive decline in hydraulic conductivity due to air embolism, microbial occlusion of xylem vessels, and physiological blockages. Microbial proliferation in vase solutions constitutes a primary cause of vascular occlusion, with bacterial populations exceeding 10^8 CFU/mL commonly observed in untreated solutions, leading to reduced water uptake and accelerated wilting (Khan *et al*., 2015; Jowkar *et al*., 2017) [21, 24]. Antimicrobial agents function primarily by inhibiting microbial growth, thereby maintaining hydraulic conductivity. Silver-based compounds demonstrate broad-spectrum antimicrobial activity, effectively suppressing bacterial and fungal proliferation in vase solutions (Liu *et al*., 2009; Abdel-Kader *et al*., 2017; Kazemipour *et al*., 2013) [2, 23, 28]. Acidification of holding solutions to pH 3.5–4.0 using citric acid reduces microbial growth while improving water uptake through enhanced xylem permeability (Othman *et al*., 2023) [31].

2. Carbohydrate Metabolism and Energy Status

Post-harvest cut flowers experience progressive carbohydrate depletion due to continued respiration without photosynthetic replenishment. Exogenous sucrose supplementation (2–4%) replenishes carbohydrate reserves, maintains cellular turgor through osmotic adjustment, and delays senescence by sustaining metabolic activities (Patel *et al*., 2021; Kshirsagar *et al*., 2021; Kumari *et al*., 2018) [25, 26, 32]. The efficacy of sucrose supplementation varies among species, with optimal concentrations ranging from 2–7%. Excessive sucrose concentrations may promote microbial growth, necessitating concurrent antimicrobial treatment (Jafarpour *et al*., 2015; Ahmad *et al*., 2013) [3, 19].

3. Ethylene Physiology and Sensitivity

Ethylene plays a central role in flower senescence, with species exhibiting varying degrees of ethylene sensitivity. Roses are classified as highly ethylene-sensitive, exhibiting rapid petal wilting, abscission, and color changes upon ethylene exposure (Ha *et al*., 2019; Chamani *et al*., 2005) [9, 14]. Chrysanthemum and gerbera show moderate to low ethylene responsiveness. Anti-ethylene strategies include silver thiosulfate (STS), which binds to ethylene receptors preventing ethylene-induced senescence; STS at 0.2–0.5 mM significantly extends vase life in ethylene-sensitive species by inhibiting ethylene production while enhancing relative water content (Hassan *et al*., 2014; Liao *et al*., 2000; Barbosa *et al*., 2005) [7, 17, 27]. 1-Methylcyclopropene (1-MCP), a gaseous ethylene action inhibitor, provides an alternative to STS with reduced environmental concerns, effectively delaying senescence in roses and other ethylene-sensitive flowers (Pietro *et al*., 2010; Spricigo *et al*., 2010) [33, 39].

4. Membrane Integrity and Oxidative Stress

Senescence involves membrane deterioration through lipid peroxidation, increased membrane permeability, and electrolyte leakage. Antioxidant compounds including salicylic acid, citric acid, and plant extracts mitigate oxidative damage by scavenging reactive oxygen species (ROS) and maintaining membrane integrity (Bayat *et al*., 2017; Shabanian *et al*., 2018) [8, 37]. Salicylic acid demonstrates multifunctional preservation effects including antioxidant activity, antimicrobial properties, and modulation of senescence-related gene expression, extending vase life across multiple species through reduced chlorophyll degradation and maintained membrane integrity.

Chemical Preservation Strategies

1. Silver-Based Compounds

Silver compounds represent the most extensively studied antimicrobial agents in cut flower preservation.

Silver Thiosulfate (STS): STS functions as both an antimicrobial agent and ethylene action inhibitor, providing dual preservation benefits particularly valuable for ethylene-sensitive species. STS at 0.2–0.5 mM applied as pulsing treatments (4–24 hours) significantly extends vase life in roses, carnations, and other ethylene-sensitive flowers through silver ion binding to ethylene receptors while simultaneously inhibiting microbial proliferation (Ohkawa *et al*., 1999; Khan *et al*., 2015) [24, 30]. In roses, STS at 0.4 mM significantly extended vase life, minimized weight loss, enhanced relative water content, and retarded chlorophyll and carbohydrate degradation while decreasing ethylene production (Hassan *et al*., 2014) [17]. In gerbera, the combination of sugar with silver thiosulfate resulted in maximum vase life extension (13.3 days), minimum petal discoloration, delayed stem bending, and increased solution uptake (Khan *et al*., 2015) [24].

Silver Nitrate ($AgNO_3$): Silver nitrate provides effective antimicrobial activity at lower concentrations (30–100 mg/L) with reduced cost and simplified application. $AgNO_3$ consistently ranks among the most effective preservation solutions across rose, gerbera, and lily species (Othman *et al*., 2023) [31]. Combination treatments incorporating silver nitrate with sucrose and other additives demonstrate synergistic effects, with formulations containing 2% sucrose + 30 ppm $AgNO_3$ + 75 mg/L boric acid achieving optimal performance in rose preservation (Kshirsagar *et al*., 2021) [25]. The antimicrobial mechanism involves silver ion interaction with microbial cell membranes, disrupting cellular functions and interfering with enzymatic activities essential for microbial metabolism.

2. Organic Acids

Citric Acid: Citric acid functions primarily through pH reduction to 3.5–4.0, inhibiting microbial growth and improving water uptake by reducing xylem blockage. Acidic holding solutions consistently demonstrate higher or equivalent vase life across rose, gerbera, and lily species (Othman *et al*., 2023) [31]. Combination treatments incorporating citric acid with aluminum sulfate and sucrose extend chrysanthemum vase life to 16 days through combined acidification, antimicrobial activity, and nutrient supplementation (Patel *et al*., 2021) [32].

Salicylic Acid: Salicylic acid exhibits multifunctional preservation properties including antioxidant activity, antimicrobial effects, and modulation of stress responses. In chrysanthemum, combination treatment of 4% sucrose with 100 ppm salicylic acid achieved maximum vase life of 18 days, significantly exceeding control treatments (Patel *et al*., 2021) [32]. The preservation mechanism involves induction of antioxidant enzyme activities, reduced ethylene production, maintained membrane integrity, and delayed chlorophyll degradation (Bayat *et al*., 2017) [8]

3. Carbohydrate Supplementation

Sucrose represents the primary carbohydrate source in preservation solutions, with optimal concentrations typically ranging from 2–7% depending on flower type (Sharma *et al*., 2015; Spricigo *et al*., 2010) [38, 39]. Sucrose alone provides inconsistent results; combination treatments incorporating antimicrobial agents and pH modifiers demonstrate superior efficacy (Othman *et al*., 2023) [31]. The standard preservation formulation of sucrose combined with silver compounds (STS, $AgNO_3$, nano-silver) provides both energy supplementation and microbial control.

4. Plant Growth Regulators

Gibberellic acid (GA_3) and benzyl adenine (BA) treatments extend vase life in gerbera through delayed senescence, maintained petal turgor, and reduced chlorophyll degradation (Danaee *et al*., 2011) [10]. Commercial preservative products containing gibberellin and benzyl adenine demonstrate significant vase life extension compared to water controls (Kaya *et al*., 2025) [22]. Calcium chloride improves vase life in gerbera by maintaining cell wall integrity, reducing membrane permeability, and delaying stem bending; pulsing treatments with calcium chloride and sucrose demonstrate superior efficacy compared to continuous holding solutions (Riaz *et al*., 2025) [34].

5. Eco-Friendly and Bio-Based Preservatives

Growing environmental concerns have stimulated research on sustainable preservation alternatives. Tea polyphenols, chitosan, and melatonin demonstrate preservation efficacy in chrysanthemum through antioxidant activity, antimicrobial effects, and modulation of senescence-related processes (Yu *et al*., 2024). Essential oils from various plant sources exhibit antimicrobial and antioxidant properties, extending vase life in multiple cut flower species (Banjaw, 2017) [2]. However, efficacy of bio-based preservatives generally remains lower than conventional chemical preservatives, requiring optimization of concentrations, application methods, and combination formulations. Integration of bio-based preservatives with reduced concentrations of silver compounds may provide balanced approaches combining sustainability with adequate preservation efficacy.

Nanotechnology-Based Preservation

1. Nano-Silver: Properties and Mechanisms

Nano-silver particles (1–100 nm diameter) exhibit unique physicochemical properties including high surface area-to-volume ratio, enhanced reactivity, and sustained silver ion release. The antimicrobial mechanism involves: (1) sustained release of silver ions disrupting microbial cell membranes; (2) direct nanoparticle interaction with microbial cell walls; (3) generation of reactive oxygen species inducing oxidative stress in microorganisms; and (4) interference with DNA replication and protein synthesis (Liu *et al*., 2009; Abdel-Kader *et al*., 2017) [2, 28].

2. Efficacy Across Species

Nano-silver treatments demonstrate consistent vase life extension across roses, carnations, gerbera, and chrysanthemum. Both pulse and continuous vase solution treatments with nano-silver extend vase life, with combination treatments incorporating nano-silver and sucrose providing superior preservation compared to individual treatments (Liu *et al*., 2009) [28].

In roses, nano-silver treatments at 5–30 mg/L alleviate harmful effects of exogenous ethylene, preventing quick wilting, early leaf abscission, and inhibited flower opening (Hong-mei, 2012) [18]. Nano-silver application significantly improves vase life and controls microbial proliferation with complete inhibition of microbial growth observed during initial preservation periods (Jowkar *et al*., 2013; Jowkar *et al*., 2017) [20, 21]. In gerbera, nano-silver demonstrates significant vase life extension, improved flower quality, reduced stem bending, and maintained fresh weight (Safa *et al*., 2012; Safa *et al*., 2015) [35, 36]. Combination treatments of nano-silver with calcium chloride provide synergistic effects through concurrent antimicrobial activity and structural support (Geshnizjany *et al*., 2014) [13]. In chrysanthemum, nano-silver extends vase life through antimicrobial activity and reduced ethylene sensitivity (Kazemipour *et al*., 2013) [23].

3. Nano-Silver versus Conventional Silver Compounds

Comparative studies demonstrate variable results depending on species, cultivar, and experimental conditions. Nano-silver treatments show comparable or superior efficacy to silver nitrate and STS in roses, with advantages including lower required concentrations, reduced environmental impact, and sustained antimicrobial activity (Abdel-Kader *et al*., 2015; Hashemabadi *et al*., 2014) [1, 16]. Nano-silver demonstrates superior antimicrobial efficacy compared to silver nitrate at equivalent silver concentrations, attributed to enhanced surface area, sustained ion release, and direct nanoparticle-microbe interactions. Combined nano-silver, α-aminoisobutyric acid, and 1-MCP treatment delays senescence in roses with different ethylene sensitivities, providing comprehensive preservation through antimicrobial activity, ethylene inhibition, and metabolic modulation (Ha *et al*., 2022) [15]. Cold storage combined with nano-silver treatment significantly improves post-harvest quality of gerbera through synergistic effects of reduced temperature and antimicrobial activity (Anonymous, 2025) [5]. Despite proven efficacy, cost considerations and lack of standardized characterization protocols currently limit widespread commercial adoption of nano-silver.

Species-Specific Preservation Requirements

1. Rose (*Rosa hybrida*)

Roses are highly ethylene-sensitive, with post-harvest senescence involving rapid petal wilting, color changes, leaf abscission, and bent neck syndrome. Effective preservation incorporates: (1) anti-ethylene treatments (STS, 1-MCP, nano-silver); (2) antimicrobial agents to maintain hydraulic conductivity; (3) carbohydrate supplementation (2–4% sucrose); and (4) pH optimization (3.5–4.0) (Ha *et al*., 2019; Chamani *et al*., 2005; Minde, 2019) [9, 29]. STS at 0.4 mM represents a standard anti-ethylene treatment, significantly extending vase life through ethylene inhibition and antimicrobial activity (Hassan *et al*., 2014) [17]. Formulations containing 2% sucrose + 30 ppm $AgNO_3$ + 75 mg/L boric acid achieve superior preservation performance (Kshirsagar *et al*., 2021) [25]. Nano-silver at 5–30 mg/L provides effective alternatives to conventional silver compounds, with combined nano-silver and 1-MCP offering comprehensive preservation for roses with varying ethylene sensitivities (Abdel-Kader *et al*., 2017; Hong-mei, 2012) [2, 18]. Cold storage at 4°C combined with chemical preservatives extends rose vase life 3–4 fold compared to ambient conditions (Othman *et al*., 2023) [31].

2. Gerbera (*Gerbera jamesonii*)

Gerbera exhibits characteristic senescence including stem bending, petal wilting, and color fading. Stem bending—caused by weakening of peduncle tissues and gravitropic responses—represents the primary quality limitation requiring specific interventions. Effective gerbera preservation strategies incorporate: (1) calcium supplementation to maintain cell wall integrity and reduce stem bending; (2) antimicrobial agents to prevent vascular occlusion; (3) carbohydrate sources; and (4) plant growth regulators (Danaee *et al*., 2011; Danaee *et al*., 2016) [10, 11]. Calcium chloride pulsing treatments combined with sucrose significantly improve vase life by maintaining structural integrity, demonstrating superior efficacy compared to continuous holding solutions (Riaz *et al*., 2025) [34]. Nano-silver combination treatments with calcium chloride provide synergistic preservation effects (Safa *et al*., 2012; Geshnizjany *et al*., 2014) [13, 18]. Commercial preservatives containing gibberellin and benzyl adenine demonstrate significant vase life extension (Kaya *et al*., 2025) [22]. Acidic holding solutions (pH 3.5–4.0) consistently improve gerbera vase life compared to neutral or basic solutions (Othman *et al*., 2023) [31].

3. Chrysanthemum (*Chrysanthemum morifolium*)

Chrysanthemum exhibits moderate ethylene sensitivity with senescence characterized by petal wilting, discoloration, and leaf browning, demonstrating favorable responses to diverse chemical treatments. Effective preservation incorporates: (1) combination treatments of sucrose with organic acids (salicylic acid, citric acid); (2) antimicrobial agents including silver compounds and aluminum sulfate; and (3) eco-friendly preservatives (Patel *et al*., 2021; Anonymous, 2024) [4, 32]. Combination treatment of 4% sucrose with 100 ppm salicylic acid achieves maximum vase life of 18 days, significantly exceeding controls (Patel *et al*., 2021) [32]. Ethylene action inhibitors including 1-MCP and STS extend chrysanthemum vase life, though efficacy varies among cultivars (Spricigo *et al*., 2010; Florez-Roncancio *et al*., 1996) [12, 39]. Nano-silver demonstrates effective preservation through antimicrobial activity and reduced ethylene sensitivity (Kazemipour *et al*., 2013) [23]. Eco-friendly preservatives including tea polyphenols, chitosan, and melatonin extend vase life through antioxidant activity and antimicrobial effects, representing sustainable alternatives to conventional preservatives (Yu *et al*., 2024).

4. Tuberose (*Polianthes tuberosa*)

Tuberose is an important fragrant cut flower with limited research coverage compared to rose, gerbera, and chrysanthemum. Available evidence indicates tuberose responds favorably to standard preservation treatments including sucrose supplementation, antimicrobial agents, and pH optimization. Preservative solutions containing sucrose, citric acid, and antimicrobial agents extend tuberose vase life through maintained water relations, carbohydrate supplementation, and reduced microbial proliferation (Kumari *et al*., 2018) [26]. Species-specific optimization studies remain limited, representing a significant research gap requiring further investigation.

Integrated Preservation Systems, Comparative Efficacy, and Environmental Factors

1. Multi-Component Preservation Formulations

Comparative analyses consistently demonstrate that multi-component formulations outperform single-agent treatments across all cut flower species. Effective integrated systems typically incorporate: (1) carbohydrate source (2–4% sucrose); (2) antimicrobial agent (silver compounds or organic acids); (3) pH modifier (citric acid, pH 3.5–4.0); and (4) species-specific additives such as calcium for gerbera or anti-ethylene compounds for roses. Commercial preservative products containing sugar, bactericides, fungicides, and pH modifiers consistently demonstrate superior preservation efficacy across rose, gerbera, and lily species (Othman *et al*., 2023) [31]. Synergistic effects of multiple preservation agents simultaneously address diverse senescence mechanisms, providing comprehensive preservation superior to individual treatments.

Quantitative analysis of vase life extension across reviewed studies indicates: silver-based compounds yield 30–60% improvement over water controls; nano-silver treatments achieve 40–70% extension with superior efficacy at lower concentrations; multi-component commercial preservatives provide 50–100% extension; and combination treatments achieve 60–120% extension depending on formulation and species. The most substantial improvement comes from cold storage (4°C) combined with chemical preservatives, extending vase life 200–300% compared to ambient temperature storage (Othman *et al*., 2023) [31].

Comparative evaluation of antimicrobial agents across multiple studies indicates the following efficacy ranking: commercial preservatives (multi-component) > nano-silver particles > silver nitrate > silver thiosulfate > organic acids alone > water control (Kaya *et al*., 2025; Othman *et al*., 2023) [22, 31]. Nano-silver demonstrates superior antimicrobial efficacy compared to conventional silver compounds at equivalent silver concentrations, with complete inhibition of microbial growth observed during initial preservation periods (Jowkar *et al*., 2017) [21]. Silver nitrate ranks second in vase life enhancement, providing effective antimicrobial activity at moderate cost (Othman *et al*., 2023) [31].

2. Application Methods: Pulsing versus Continuous Holding

Pulsing treatments utilize higher concentrations (e.g., 0.4 mM STS, 200–400 mg/L calcium chloride) applied for 4–24 hours, followed by transfer to water or maintenance solutions. Continuous holding solutions employ lower concentrations maintained throughout vase life. Comparative studies indicate pulsing treatments with calcium chloride and sucrose combinations demonstrate superior efficacy in gerbera preservation, attributed to enhanced uptake during initial treatment periods and reduced osmotic stress during subsequent vase life (Riaz *et al*., 2025) [34]. However, continuous holding solutions provide sustained antimicrobial activity and carbohydrate supplementation, with optimal application method varying among species and preservation objectives.

3. pH Optimization and Temperature Management

Solution pH critically influences microbial growth, nutrient availability, and water uptake. Acidic solutions (pH 3.5–4.0) consistently demonstrate superior vase life across multiple species, with citric acid serving as the most commonly utilized pH modifier providing both acidification and antioxidant effects (Othman *et al*., 2023) [31]. Excessive acidification below pH 3.0 may cause tissue damage.

Temperature represents the most influential environmental factor affecting cut flower longevity. Cold storage at 4±1°C significantly extends vase life by slowing metabolic activities, reducing respiration and ethylene production, and restricting microbial proliferation. Comparative studies demonstrate cold storage extends vase life 3–4 times longer than room temperature (20±2°C) storage (Othman *et al*., 2023) [31]. Integration of cold storage with chemical preservatives provides synergistic preservation effects. Post-harvest warm water treatment (40°C) facilitates rehydration by reducing air embolism and promoting water uptake; recutting stems underwater (2.5 cm) followed by placement in low-pH holding solutions removes air blockages and enhances water relations.

Conclusions and Future Directions

Synthesis of evidence across four cut flower species reveals several universal preservation principles. Multi-component preservation systems consistently outperform single-agent treatments by addressing the multifactorial nature of post-harvest senescence. Antimicrobial activity represents a fundamental preservation requirement, with silver compounds and organic acids effectively maintaining hydraulic conductivity. pH optimization (3.5–4.0) enhances preservation efficacy through concurrent antimicrobial and nutrient availability benefits. Carbohydrate supplementation (2–4% sucrose) sustains metabolic activities but requires concurrent antimicrobial treatment for consistent results. Temperature management—particularly cold storage at 4°C—provides the single most substantial preservation improvement.

Despite universal principles, species-specific physiological differences necessitate tailored strategies. Roses require anti-ethylene treatments (STS, 1-MCP) due to high ethylene sensitivity. Gerbera necessitates calcium supplementation to address characteristic stem bending. Chrysanthemum benefits from organic acid combinations, particularly salicylic acid. Tuberose remains understudied, representing a priority research area.

Nano-silver particles represent a promising technology offering enhanced antimicrobial efficacy at lower silver concentrations, with demonstrated efficacy across all four species. However, cost considerations, lack of standardized characterization protocols, and incompletely evaluated environmental fate currently limit commercial adoption. Future research should prioritize: (1) species-specific optimization of nano-silver concentrations and formulations; (2) development of sustainable bio-based preservatives with efficacy comparable to conventional chemicals; (3) mechanistic investigation of nano-silver preservation effects beyond antimicrobial activity; (4) species-specific studies on tuberose preservation requirements; (5) integration of machine learning and meta-analytical approaches for systematic optimization of preservation formulations (Wu *et al*., 2025); and (6) regulatory evaluation of nanomaterial applications in floriculture.

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