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REVIEW ARTICLE

Nanotechnology in floriculture: Extending vase life and improving postharvest quality

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Abstract

Cut flowers are traditionally used worldwide, regardless of caste, creed, and religion, especially in Asian countries. The global trade of cut flowers has shown a substantial increase in recent years and is expected to persist due to the promotion and application of horticulture plants for their various advantages. The quality of vase life is critical in ensuring customer satisfaction and encouraging repeat purchases. Effective postharvest management is essential for enhancing the quality and extending the shelf life of cut flowers. With proper handling, cut flowers can last several days in a vase. Nanotechnology presents innovative solutions for postharvest management, especially in the cut flower sector. Specifically, Nanoparticles have been utilized in packaging to act as ethylene inhibitors and antimicrobial agents, contributing to the extension of cut flower vase life. One of the strongest ethylene perceptions is 1-methylcyclopropene (1-MCP), a gaseous and nontoxic that binds to ethylene receptors irreversibly, blocking the action of ethylene. Nano-Silver particles improve postharvest longevity by increasing water absorption rather than transpiration. Additionally, Nano-Selenium enhances the water balance in cut flowers. This review describes how nanoparticles suppress microbial growth and block ethylene action in cut flowers, extending their vase life.

Keywords

antimicrobial activity; ethylene reduction; nanoparticles; pulsing solution; vase life

Introduction

The popularity of fresh-cut flowers has grown as people's living standards have increased, with cut roses ranking first in the cut flower list (1). Nevertheless, the postharvest longevity of cut flowers is exceedingly brief, typically enduring only a few days in a vase (2). A key factor influencing the appeal of fresh-cut flowers is their vase life (3). Consequently, postharvest loss is a significant challenge encountered by the global floriculture business. It is estimated that postharvest loss of cut flowers ranges between 10 to 30%. Prolonging the vase life of cut flowers is paramount in minimizing these losses and maximizing the industry's economic potential. Extending the vase life of cut flowers offers clear advantages to retailers by minimizing waste, improving customer satisfaction and enabling more efficient inventory control, ultimately boosting sales. For consumers, everlasting flowers enhance the delight and perceived value of their purchase, promoting repeat purchases and cultivating brand loyalty. Moreover, an extended vase life in international trade reduces losses during transportation. It ensures that flowers reach their destination in peak condition, providing a competitive edge in the global marketplace. Thus, proper management of vase life is vital for all sectors of the floral industry (4). Nanotechnology is crucial in enhancing output by improving input efficiency and reducing pertinent losses (4). Fresh-cut flowers have a longer vase life because of nanomaterials' superior water absorption and antibacterial properties, which have demonstrated beneficial effects in their preservation (5). Additionally, nanomaterials enhance the activity of antioxidant enzymes and influence plant hormone concentrations. For instance, graphene oxide (GO) has been shown to significantly improve water retention in plants, although research on using nanomaterials in flower preservation remains limited (6). Chitosan (CS) material mitigates the detrimental effects of oxidative stress, commonly experienced post-harvest, by enhancing total phenolics, sugar levels and antioxidant capacity. It is widely used in creating edible coatings due to its ability to form a semipermeable film that delays quality deterioration. Chitosan coatings enhance the permeability of stored products while restricting the exchange of oxygen (O_2), carbon dioxide (CO_2), and hydrogen peroxide (H_2O_2). Moreover, its application has benefited certain cut flowers, such as roses and *Heliconia bihai* (7). 1-Methylcyclopropene is widely used in flower crops to inhibit ethylene, a hormone responsible for senescence and wilting. By binding to ethylene receptors, 1-MCP prevents the hormone from initiating these aging processes, thus extending the vase life of flowers. It has proven effective in many flower species, including roses, carnations, lilies and chrysanthemums, where it delays petal wilting, leaf yellowing and other ethylene-induced effects. This technology is crucial for maintaining flower quality during postharvest storage and transportation, ensuring longer freshness for various flower crops (8) (Fig. 1).

Maintaining the quality of the flowers after harvesting them is an essential process in creating the damask flowers' volatile oil. Certain techniques, such as cold storage and drying, have been tried with mixed results in regulating the postharvest quality of flowers. Regrettably, storing freshly harvested flowers in a refrigerator may cause chilling injuries. In this case, cold storage alone was not a prudent way to prevent these injuries. Finding alternate methods to maintain the quality of flowers is necessary to enhance the vase life and profit of the cut flowers industry (9). Additionally, strategies are required to improve the reliability for cut flowers lasting for a minimum duration, which is crucial not only for sustainability but also for the growth of the horticultural sector (10). Hydrogen nanobubble water (HNW) has shown higher antioxidant activity than regular hydrogen-rich water, making it a valuable tool in postharvest preservation (11). Nanoparticles also enhance the color of cut flowers, which is a critical factor for customers' acceptance. Sodium nitroprusside (SNP), a nitric oxide donor with various mechanisms affecting vase life, is notably important. In fact, it has been found to prolong the vase life of several cut flowers, including carnations, gladiolus and roses (12). Magnesium oxide nanoparticles (MgONPs) exhibit potent antimicrobial properties and have been recognized as safe by the U.S. Food and Drug Administration. Serving as ethylene biosynthesis inhibitors, MgONPs enhance the petal quality of cut lotus flowers (*Nelumbo nucifera*) by suppressing the expression of 1-aminocyclopropane-1-carboxylic acid synthase (ACS) and 1-amino-cyclopropane-1- carboxylic acid oxidase (ACO) genes, thereby preventing petal darkening (13). This review documents the impact of nanoparticles in enhancing the vase life of different cut flowers (Table 1).

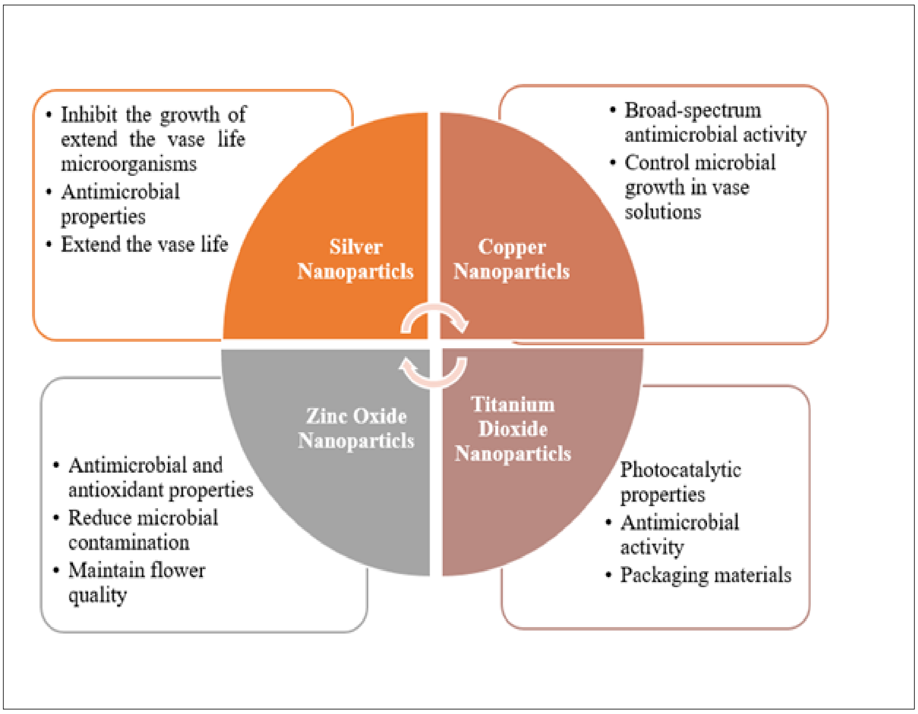

Fig.1. Activity of nano preservatives.

Table 1. Role of preservatives in flower crops

S. No.	Preservatives	Crop	Outcome	Reference
1.	1- Methylcyclopropene	*Dahlia*	Significantly extends the vase life of cut flowers by blocking ethylene receptors, thereby delaying wilting and senescence. This treatment helps maintain flower quality and freshness for a longer period.	(14)
2.	Silicon nanoparticles (Si-NPs)	Lilium	Increase flower quality and shelf life. Improve water retention and reduce ethylene sensitivity to enhance flower longevity and quality.	(15)
3.	Silica nanoparticles	Carnation	Silicon nanoparticles improve water retention and nutrient uptake, SiO_2, NPs can help prolong the vase life of carnations, maintain their vibrant color, and reduce ethylene sensitivity, ultimately leading to better floral displays.	(16)
4.	Calcium-silicon nanoparticles	Lilium	These nanoparticles can improve calcium availability, strengthen cell walls, and enhance resistance to stress, leading to prolonged vase life and better overall flower health.	(17)
5.	SiO_2 and calcium chelate (Ca-chelate)	*Gerbera*	Enhance nutrient uptake and improve overall plant health, leading to increased flower quality, extended vase life, and enhanced resistance to stress factors in postharvest conditions.	(18)
6.	Aluminum sulfate ($Al_2(SO_4)_3$)	Chrysanthemum	This compound can promote better growth, vibrant flower color, and extended vase life by aiding in the uptake of essential nutrients, ultimately contributing to the overall quality of the blooms.	(19)

Use of nanoparticles in postharvest management of cut flower crops

Nano materials for packaging of cut flowers

Nano packing materials offer an appealing substitute for preserving flower crops, while conventional packing materials can be more expensive, time-consuming and alter flavor and color. It is currently necessary that nano packaging employs nanomaterials that improve barrier properties, enhance mechanical strength and incorporate active components that prevent spoilage. Unlike traditional packaging, which primarily serves as a physical barrier, nano packaging can interact with products by releasing antimicrobial agents and utilizing smart sensors for real-time monitoring. This technology allows for thinner, more efficient materials, leading to reduced waste and tailored solutions for specific preservation needs. Overall, nano packaging offers superior protection and functionality compared to conventional methods. Nanotechnology will take time to succeed (20, 21). A simple antimicrobial packaging method has been developed to enhance the shelf life of cut roses during storage and transport while minimizing variations caused by handling protocols. This approach employs freshness keeper (FK) paper, which creates a protective barrier that prevents microbial growth on the surfaces of the flowers. Additionally, further research has explored the antimicrobial properties of various natural herbs and spices to devise effective strategies for maintaining freshness and extending the shelf life of cut roses. A range of extracts from spices and herbs were investigated for their ability to prevent spoilage microorganisms from growing on the surface of the roses. These natural extracts provide antimicrobial protection, which gives them an advantage over conventional chemical-based preservatives. Their application also corresponds with the floral industry's need for environmentally friendly preservation techniques. (Table 2 and Fig. 2).

Nanoparticles in pulsing solution

Nanoparticles are widely used in vase solutions, particularly to reduce fungal pathogens. Including a few dangerous postharvest disease pathogen species (*Penicillium* and *Botrytis*) can accelerate the growth of pathogens during postharvest cut flower handling, resulting in financial loss (26). In comparison, nano-fungicides are more effective than traditional fungicides due to their enhanced penetration and slow release, which allows for prolonged protection against fungal pathogens. Nano-fungicides can target specific sites more efficiently and reduce the overall quantity of chemicals needed. Traditional fungicides, while effective, often require higher doses and frequent applications to maintain control over pathogens, which can lead to more significant environmental impact and resistance development. Therefore, cutting-edge antifungal medications must be used to fight this opposition. Due to its distinct physical and chemical characteristics, the zinc oxide nanoparticle exhibits increased heat resistance, selectivity

Table 2. Various plant extracts are utilized to make silver nanoparticles

Flower	Plant extract	Improved quality	References
Rose	Saffron petal extracts	Prevented *Bacillus* and *Pseudomons* from growing	(22)
Carnation	Saffron petal extracts	Increasing water uptake and decreased leakage of ions from petal tissues	(23)
Gerbera	Mexican tea	Antimicrobial	(24)
Chrysanthemum	Carvacrol essential oil extracted from oregano	encouraged the opening of flowers and prolonged vase life	(25)

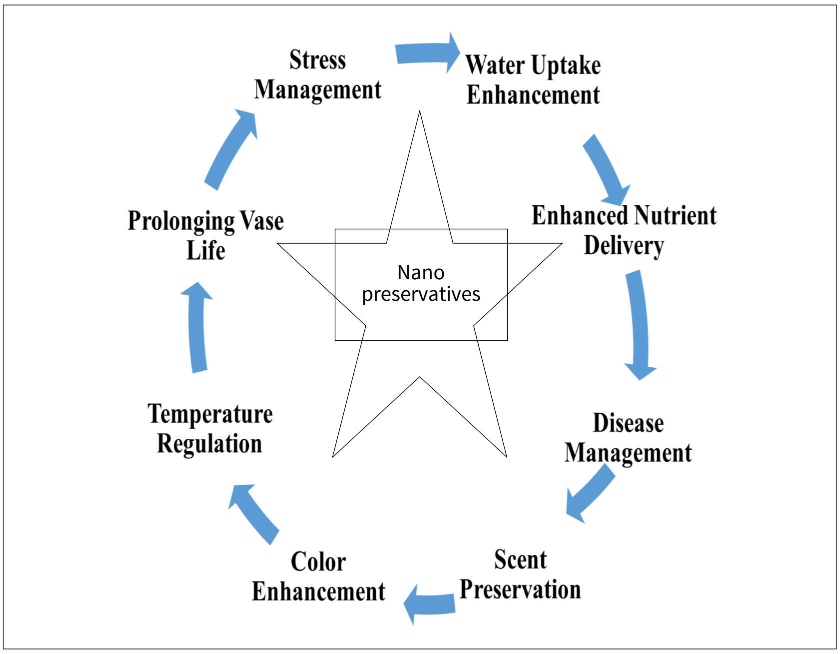

Fig. 2. Application of nano preservatives used in cut flowers.

and durability. Zinc oxide (ZnO) powder is mainly used in agriculture as a fungicide, but it also has antifungal and antibacterial qualities that have been demonstrated (27). Small zinc oxide particles, typically found in aggregates during manufacturing, can be effectively dissolved using two common methods: dispersants and ultrasonication. Common dispersants include polyethylene glycol, polyvinyl pyrrolidone and several other substances. Notably, significant antifungal activity was observed against two pathogens at a minimum ZnO concentration of 3 mmol/l, with effectiveness potentially increasing up to 12 mmol/l. In particular, nano treatment demonstrates greater efficacy against *Penicillium expansum* than *Botrytis cineraria* (28) (Table 3).

The potential of nanotechnology in extending the vase life of cut flowers

Rose

Roses, as a significant cut flower crop, occupy the foremost place worldwide owing to their substantial demand. While they are popular with flower enthusiasts, early dehydration significantly diminishes their commercial value. Chemical additives, applied both before or after harvesting, can enhance the quality of roses and extend their vase life (34). The multi-porous structure of silica nanoparticles (SiNPs) and their highly reactive surface-to-volume ratio enhance their effectiveness compared to other forms of silicon, such as silicate or silicon dioxide. However, there are environmental concerns and limitations associated with the use of SiNPs. These include potential toxicity to non-target organisms, which could disrupt beneficial microbial communities and ecosystems. Additionally, bioaccumulation is risky in the environment, leading to unknown long-term effects on soil and aquatic health. Regulatory challenges surrounding the approval and use of nanoparticles may also hinder their widespread application. Furthermore, synthesizing and disposing of SiNPs can involve hazardous chemicals, necessitating careful evaluation of their environmental impacts to promote sustainable practices (35). They also have a higher density at reactive sites. Through preserving membrane integrity, enhancing antioxidant enzyme activity, and inhibiting lipid peroxidation, SiNPs also extended the vase life of cut roses (36). 1-Methylcyclopropene enhanced antioxidant capacity, inhibited phenol oxidation, decreased ethylene production and preserved anthocyanins. Compared to the control group, the simultaneous use of 1-MCP and low temperature markedly reduced the production of H_2O_2 and O_2, electrolyte leakage and malondialdehyde (MDA) levels, while simultaneously enhancing total phenol content and the activities of antioxidant enzymes. Furthermore, there is currently no information on how 1-MCP controls the damask roses's ethylene-related senescence. Therefore, research on maintaining this economically valuable species postharvest quality during storage until oil extraction is required (37). Another potential best practice for preserving the quality of damask rose flowers is chitosan (CS). This intriguing bio-

Table 3. Concentrations of silver nanoparticles for various cut flowers to extend vase life

Cut flower	Method of application	The concentration of silver nanoparticles	Concentration of better outcomes	References
Carnation	Vase solution	5 mg L^{-1}	Decreased synthesis of ethylene	(29)
Chrysanthemum	Pulse treatment	10 mg L^{-1}	Decreased vascular occlusion and avoided dehydration	(30)
Gerbera	Pulse treatment	10 mg L^{-1}	Water content and hydraulic conductance were maintained.	(31)
Lisianthus	Vase solution	40 mg L^{-1}	Extending the vase life and quality	(32)
Mokara red orchid flower	Pulse treatment	5 mg L^{-1}	Extending the vase's life	(33)

stimulant, poly β-(1,4)-N-acetyl-D-glucosamine, is a naturally occurring cationic polysaccharide that has been demonstrated to boost the productivity of cut rose. Its natural origins are derived from the chitin shells of shrimp and other crustaceans; CS is a biocompatible, nontoxic and non-allergenic substance. Furthermore, it has demonstrated efficacy in enhancing the synthesis of secondary metabolites in many medicinal plants (38) (Fig. 3).

Carnation

Several alternative antibacterial agents have been studied for carnations, including essential oils, plant extracts and nanoparticles like ZnO and copper oxide. While nano-silver is known for its broad-spectrum antibacterial properties and often demonstrates superior efficacy against various pathogens, alternatives like essential oils (e.g., clove and tea tree) and plant extracts (e.g., garlic and neem) offer lower toxicity and environmental impact due to their biodegradability. Zinc oxide nanoparticles exhibit antibacterial effects similar to nano-silver but with potentially reduced environmental toxicity, while copper oxide nanoparticles may pose risks to aquatic life. Although nano-silver is highly efficacious, investigating these alternatives may yield more sustainable and environmentally benign postharvest treatments for carnations (35). Carnations second rank as the most popular cut flower crop globally (39). The utilization of nano-silver particles is increasingly gaining traction across various sectors, including the ornamental industry (40). These particles serve as antibacterial agents in vase or pulse solutions, effectively prolonging the vase life of cut flowers (41). Various compounds, including silver nitrate ($AgNO_3$), aluminum sulfate ($Al_2(SO_4)_3$) and 8-hydroxyquinoline sulfate, are employed to improve water absorption in carnations (42). Given silver's antimicrobial properties, certain silver-containing compounds can be employed alongside ethylene inhibitors to prevent xylem blockages and inhibit the growth of bacteria and other microorganisms (29). Nanoscale silver particles are excellent in combating bacteria and other pathogens. The application of nanotechnology or nano silver particles in vase or pulse solutions is innovative, as they possess antibacterial qualities (43) (Fig. 4.) The study investigated the roles of water relations, the bacterial strain Enterobacter cloacae and nano-silver in cut carnations. Ethylene inhibitors, including silver thiosulfate, 1-MCP, and nitric oxide improve the vase life of flowers by decreasing the expression of genes associated with ethylene biosynthesis (44). In addition to suppressing genes related to ethylene biosynthesis, silver ions can inhibit the growth of bacteria at the cut ends, thereby enhancing flower longevity. The research concluded that a concentration of 25 mg/l of silver ions produced the most effective results in treated flowers (45). Moreover, several cut flowers, such as *Gerbera*, *Gladiolus* and rose, have demonstrated that silver ions prolong their vase life (46). The impact of silver nanoparticles (AgNPs) as anti-ethylene agents on the vase life of carnations has demonstrated that the bacterium *E. cloacae*, isolated from stem segments, significantly influences plant diseases and the biocontrol of microorganisms responsible for petal senescence (47). Immersing cut carnation stems in an SNPs solution (synthesized from *Artemisia annua* callus) prevented stem end blockage and contamination of the vase solution with four different bacterial strains and suppressed ethylene

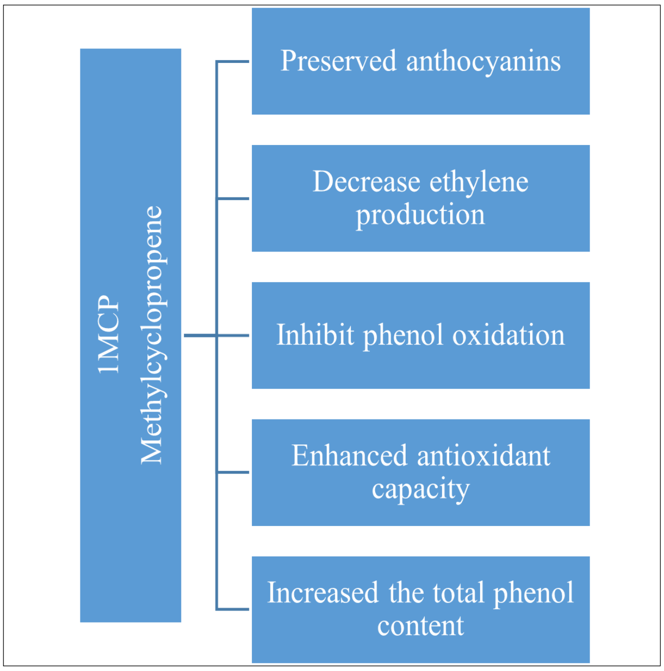

Fig. 3. Influence of 1-MCP on vase life extension and quality management of cut flower.

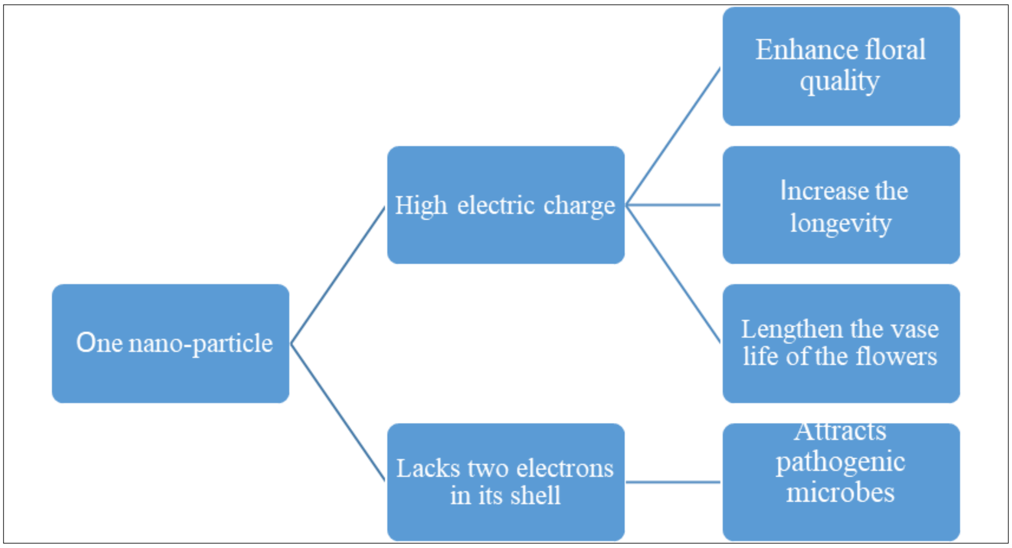

Fig.4. Mode of action of nanoparticles to extend vase life.

production (48). Cut flower water balance was improved by nano-selenium by increasing water absorption rather than transpiration. Because enzymatic and non-enzymatic antioxidants were up-regulated, nano-Se reduced lipid peroxidation, electrolyte leakage and chlorophyll degradation. To sum up, the extension of vase life caused by nano-Se has been linked to enhanced antioxidant status and better water relations, making it an inexpensive and safe way to extend the life of carnation without harming the environment (10). Hydrogen nanobubble water might delay the senescence of cut carnation flowers (49).

Gerbera

Microbial contamination in vase solutions or at the stem base significantly reduces the vase life of cut flowers, as bacteria on the cut surface can cause vessel blockages. Moreover, numerous *Gerbera* cultivars have diminished vase life due to stem bending, especially during the initial stages (50). To investigate the impact of SNP on delaying stem bending in the *Gerbera* cultivars Alliance, Rosalin and Bintang, we assessed relative fresh weight, bacterial density in the vase solution, transcriptional analysis of a lignin biosynthesis gene, antioxidant activity and xylem obstruction (51). As a novel pulse or vase solution compound, nano silver particles have antibacterial properties (43). All three cultivars exhibited delayed stem bending in response to SNP compared to the control group. Furthermore, adding two antimicrobial compounds to the vase solution can help reduce bacterial growth. Nano-silver particles, recognized for their antibacterial properties, serve as a novel option for pulse or vase solutions (52). Additionally, acetylsalicylic acid and AgNPs have enhanced postharvest longevity in carnations. Acetylsalicylic acid, a well-known phenolic compound, can modulate the levels of antioxidant enzymes and reactive oxygen species (ROS) (53). Nano silver particles inhibit postharvest bacterial growth. An alternative to the chemicals used in the *Gerbera* vase solution is the introduction of nano silver particles and nanotechnology. The primary causes of the lower quality of cut *Gerbera* are xylem blockage and the buildup of microorganisms in the vase solution (54). Nano silver particles, recognized as one of the most potent preservatives, can significantly inhibit microbial growth in vase solutions. The use of silver thiosulfate effectively suppresses ethylene-mediated physiological processes, such as flower senescence and abscission. Moreover, treating *Gerbera* flowers with nano silver pulses helps prevent bacterial growth in both the vase solution and at the cut ends of the stems (55). The impact of calcium chloride and nano silver particles on cutting *Gerbera* increases postharvest life (56). Cut *Gerbera* flowers have a limited vase life and are susceptible to microbial contamination. Silver nanoparticles are employed as an antimicrobial agent in a variety of applications. An experiment was carried out on different SNP and chlorophenol concentrations and the outcome showed that SNP and chlorophenol could improve postharvest quality and prolong vase life (57).

Gladiolus

The application of nanoparticles is rapidly expanding across various domains, including medicine, agriculture, electronics and environmental science. In medicine, nanoparticles are utilized for targeted drug delivery, diagnostic imaging and cancer treatment, enhancing therapeutic efficacy while minimizing side effects. In agriculture, they improve crop protection and nutrient delivery, offering sustainable solutions to enhance yield and reduce chemical usage. In electronics, nanoparticles are crucial in developing smaller, more efficient components, such as transistors and sensors. Additionally, in environmental research, they are utilized in water purification and pollution remediation, demonstrating their versatility and capacity to tackle modern issues across several domains (58). *Gladiolus* striking flower spikes have made it a dominant feature in the global cut flower weathering process, which is primarily related to floret death (59). Although there is great potential in the flower industry due to the toxic effects of silver particles on microorganisms, there are concerns regarding the environment and broader issues. Using plant extract is effective because it is both economical and environmentally beneficial. The majority of cut flowers have stem blockage and associated water shortage due to live bacteria and their breakdown products (60). For cut spikes to have a longer vase life, membrane stability and water balance are also crucial ROS, however, they have an immediate impact on cell membrane stability. In cut flowers, harvesting them at the bud stage helps to reduce postharvest losses, but this requires a steady supply of food and water to support flower bud growth. Therefore, carbohydrates or stored food are required to preserve cell turgor, optimize turgor pressure, maintain water balance and support the storage of food in the flower spike. The vase life of cut spikes is also impacted by the soluble salt content because stored carbohydrates provide energy for the growth of flowers and the opening of buds. The *Gladiolus* stem ends were treated with nano silver particles to reduce bacterial colonization and biofilm formation. The beautiful *Gladiolus* flower spikes have made it a dominant feature in the global cut flower weathering of perianth, primarily related to floret death. It is instructed that there are various causes for xylem cultivation, bacterial growth, physiological plugging and stem end blockage (61). Short vase life in *Gladiolus* cut spikes is a major issue linked to poor water relations (62). One common theory regarding the vascular interruption of cut flowers submerged in water is that bacterial growth at the cut ends of the stem contributes to blockage and wilting. It was discovered that bacterial cells in the form of biofilm at the stem end causes vascular blockage and rapid shriveling in cut flowers. Applying antimicrobial compounds before or after pulse treatment can minimize stem blockage and prolong vase life for most cut flowers and foliage. When used as a pulse treatment, nano-silver particles significantly extend the vase life of cut *Gladiolus* compared to other methods. Because SNPs from betel leaves (*Piper betle*) function as both a bactericide and a signaling molecule to scavenge ROS and prevent lipid peroxidation, they were able to prolong the vase life of *Gladiolus* (63).

Chrysanthemum

Chrysanthemums are prone to yellowing leaves, wilting, and incomplete flower opening. A pulsing solution is one of the postharvest technologies that can address these issues. To prolong vase life and preserve quality, it is advisable to utilize these materials in a pulsing solution (24). Pulsing solutions enhanced with ZnO or $AgNO_3$ are known to prolong vase life and preserve the quality of cut flowers. While both agents effectively inhibit microbial growth and improve water uptake, their performance can vary. Silver nitrate is widely recognized for its strong antimicrobial properties and ability to reduce ethylene production, enhancing flower longevity (64). However, it may present toxicity concerns, particularly regarding environmental impact and potential toxicity to aquatic organisms. On the other hand, ZnO offers a more environmentally friendly alternative with lower toxicity levels while still providing antimicrobial benefits and promoting overall plant health. Additionally, ZnO may enhance the resistance of flowers to various stresses. Ultimately, the choice between ZnO and $AgNO_3$ may depend on specific postharvest conditions and environmental considerations. By balancing osmotic regulation, Ag particles formulated as a pulsing solution can expand flower openings, prolong vase life, and restore stem and flower size or petal color. Certain enzymes that can control antioxidant activity and lengthen the vase life of chrysanthemums are activated by zinc (Zn). The synthesis of AgNPs requires many surfactants and presents challenges in processing, separating and purifying nanoparticles from micro-emulsions, leading to several drawbacks. On the other hand, green synthesis, which uses fewer hazardous chemicals harmful to the environment, is a more sustainable option. The green synthesis of nanoparticles utilizing plant extracts is a cost-effective, hygienic, simple and eco-friendly approach (65). Synthesized SNPs have increased chrysanthemum (*Dendranthema grandiflora*) flower opening and vase life (66). Another SNP treatment using colloidal silver (0.02%) enhanced the greenness index in cut leaves and decreased weight loss in postharvest chrysanthemums (*Chrysanthemum morifolium*). Chrysanthemums are prone to yellowing leaves, wilting and incomplete flower opening. Using a pulsing solution is one of the postharvest technologies to address these issues. To prolong vase life and preserve quality, it is advisable to utilize these materials in a pulsing solution (67). Pulsing solutions enhanced with ZnO or $AgNO_3$ are known to prolong vase life and preserve the quality of cut flowers. While both agents effectively inhibit microbial growth and improve water uptake, their performance can vary. $AgNO_3$ is widely recognized for its potent antimicrobial properties and ability to reduce ethylene production, enhancing flower longevity (24). The pulsing solution included $AgNO_3$, nano-silver (NAg), ZnO and nano-zinc (NZn) have been utilized for chrysanthemums. The results indicated that the NAg20 treatment prolonged the vase life of cut Chrysanthemum flowers to 23 days, representing a 19-day improvement compared to the control. This treatment also affected carotenoids; bacterial growth, flower wilting and color degradation are all inhibited by nano-Ag. Furthermore, nano-Ag expanded the bloom-flower diameter. When all postharvest quality parameters are taken into account, NAg20 extends the vase life of cut chrysanthemum flowers (68). Nanobubbles are used in the Chrysanthemum postharvest study. Nano/ultrafine bubbles (NBs) are tiny bubbles with a diameter of less than 1 μm (69). The study was demonstrated in cut Chrysanthemum (*Chrysanthemum morifolium*); flowers were kept in a vase of water containing air NBs to assess the mechanism by which NBs preserve the freshness of cut flowers. The cut flower's vase life was evaluated by evaluating the state of their petals and leaves. The inflorescences, petal senescence, and bud opening were postponed by the NB treatment (35). These results suggest that cutting chrysanthemum flowers treated with NB had a longer vase life due to the inhibition of transpiration from leaves (70). In this treatment, the application of NB significantly decreased transpiration without causing the stomata to close. This finding raises the possibility that the reason for the observed reduction in transpiration in the NB-treated plants was the suppression of cuticular transpiration, which is the loss of water through the epidermis (70).

Tuberose

Additional research has concentrated on the impact of various vase chemicals in enhancing the postharvest quality and vase life of tuberose (32). Tuberose, a highly valued crop that is renowned for its bulbous blossoms, has a variety of uses, such as serving as loose or cut flowers and in the perfumery industry. However, the perishable nature of tuberose cut flowers renders them vulnerable to postharvest losses. To improve their quality and prolong vase life, various treatments have been administered to the harvested flowers. In addition to a 4% sucrose solution, seven treatments were tested: $AgNO_3$ (100 ppm and 200 ppm), $Al_2(SO_4)_3$ (200 ppm and 400 ppm), citric acid (50 ppm and 100 ppm) and distilled water as a control. The combination of 4% sucrose and 200 mg of ($Al_2(SO_4)_3$) resulted in a longer vase life than the other treatments (71). This could be due to the optimal energy supply at the cut end of the spikes, as this energy accelerates the rate at which florets open. The lower pH level of the petals and the acidification of the holding solution could be additional factors contributing to the longer vase life of cut flowers. Less bacteria grows at the spikes cut ends, improving water absorption. However, various solutions of sucrose, calcium sulfate and $AgNO_3$ were recommended to lengthen the vase life of tuberose (23). Chemical preservatives (Sucrose (4%) - 100 ml, Silver nano (140 ppm) - 300 ml, $Al_2(SO_4)_3$ - 800 ppm - 300 ml and $CoCl_2$ (75 ppm) - 300 ml) were applied to them. After immersion in the chemicals, the spikes were stored at room temperature and in a cold chamber (8°C). Various storage techniques, including wet and dry storage, are used. After six days, measurements were made of the spike's dry weight, the amount of chemical preservatives they had consumed and their vase life (72).

Bird of paradise

The Bird of Paradise is a prominent tropical cut flower that requires high pre- and post-harvest quality for success in the commercial ornamental market. Silver nanoparticles and GO were introduced as novel treatments to enhance postharvest longevity and increase marketability. These nanoparticle solutions were applied at lower concentrations in vase water. As a result, the vase life of the cut flowers was extended by 6 days compared to the control group, showing better performance than treatments with deionized water (DI). The improved outcomes were linked to enhanced relative water uptake, maintained fresh weight, reduced microbial density at the stem end, delayed stem blockage and lower levels of electrolyte leakage, MDA, superoxide dismutase (SOD) and peroxidase (POD) activity (73).

Orchid

The white crane orchid, a native species of Taiwan, is celebrated for its elegant inflorescence, distinctive flowering pattern, and pure white blooms, giving it high ornamental value. A study examined the growth and blooming of its inflorescence in deionized water to determine its suitability for cut flower production. The raceme blooms sequentially from the bottom to the top, with up to thirty florets per stem, where over 20 florets typically open before the lowest one begins to wilt. Early signs of senescence include yellowing of the labellum and darkening of the anther cap. The application of ethylene inhibitors, such as silver thiosulfate (STS) or 1-MCP, on harvested inflorescences can extend their vase life to 8 days and 10 days, respectively, compared to only 6 days without treatment (8).

Lisianthus

The observed improvement in vase life across different cultivars of Lisianthus treated with nano-silver and nano-silica particles may not be consistent in all trials. Variability in results can arise due to differences in the specific cultivars tested, environmental conditions and nanoparticle concentrations or formulations. While some studies may demonstrate significant benefits in vase life and quality for certain cultivars, others may yield mixed or negligible results. Generalizing these findings to other Lisianthus cultivars not included in the study should be cautiously approached. Each cultivar may exhibit unique physiological and biochemical responses to nano-particle treatments, influenced by genetic makeup, flower morphology and postharvest handling practices. Therefore, further research involving a broader range of cultivars is necessary to draw more definitive conclusions about the effectiveness of nano-silver and nano-silica particles in extending vase life across different Lisianthus varieties.

Lisianthus ranks among the most sought-after cut flower varieties globally and it is appreciated for its multi-flowered stems and rose-like blooms, which can be single, semi-double, or double and are available in a wide range of colors. The postharvest longevity differs for each cultivar (14). The senescence of Lisianthus flowers is caused by ethylene. Flowers lived longer when treated with ethylene action inhibitors like salicylic acid (SA) or silver thiosulphate or 1-MCP. Acetaldehydes beneficial effects on lowering ethylene synthesis and increasing lisianthus longevity were observed (15). The NS preservative combined with sucrose seems to enhance the general state of Lisianthus flowers and increase their vase life. *Lisianthus* cut flowers treated with 40 mg L^{-1} of nano-silver and 40 mg L^{-1} of nano-silica particles had a 17-day extension in shelf life compared to control flowers (14). Improvements in postharvest characteristics were observed when exposed to ZnO and zinc graphene oxide ((Zn-GO). These enhancements included increased water retention, higher turgor pressure in the leaves, better flower opening, pedicel firmness maintenance and preserved green coloration in the leaves (16).

Lilium

The lily, a perennial bulbous herb from China, is extensively grown as an ornamental plant for pots and gardens and as cut flowers. It belongs to the Lilium genus in the Liliaceae family and is found in Asia, Europe and America. Also, lilies have applications in the food and pharmaceutical industries (17). However, their limited shelf life before and after harvest results in rapid deterioration, making long-distance transport challenging and diminishing market value. Consequently, it is essential to maintain flower quality and extend their shelf life. These factors are also economically important for successfully commercializing lilies (18). Thus, using SiO_2-NPs in flower production, for example, growing lilies and other commercially valuable species, may greatly enhance flower quality and prolong flower shelf life.

Conclusion and Future Prospects

The addition of silver and other metal nanoparticles can enhance postharvest qualities of cut flowers. These materials are great for preservative components because of their large surface area, durability, ease of application and lack of toxicity. Through the inhibition of ethylene production, the prevention of protein and chlorophyll breakdown, the reduction of bacterial growth and the enhancement of antioxidant enzyme activity to mitigate oxidative stress, they have effectively prolonged the vase life of cut flowers. The demand for cut flowers is expected to grow due to several factors, such as population growth, urbanization and increasing disposable incomes. Flowers are used not only for decoration but also for gifting, ceremonies in different cultures and religions and events. As international trade rises, the market for cut flowers is spreading beyond geographical boundaries. Growers around the globe now have the chance to expand into new markets and broaden their product offerings to this development. In conclusion, the future of cut flowers appears promising, as demand is maintained by a growing market, evolving consumer preferences, technological advancements and a growing emphasis on sustainability and innovation. Growers will prosper in the changing cut flower market if they adjust to these trends and invest in quality, diversity and sustainability. Additional nanoparticles possessing antimicrobial qualities could be employed to improve the overall quality of cut flowers, as well as their mobility and shelf life. The future of nano preservatives in postharvest technology holds great potential, especially in enhancing the shelf life and quality of perishable products like flowers, fruits and vegetables. Nanotechnology enables the development of more efficient and targeted preservation techniques by delivering active compounds, such as antimicrobial agents, in a controlled manner at the molecular level. This could reduce the need for synthetic chemicals, making preservation methods more environmentally friendly and less harmful to human health. Additionally, the ability to engineer nanomaterials for specific purposes, such as UV protection or gas regulation, could revolutionize how we maintain freshness, reduce spoilage and minimize waste in the agricultural and floral industries. As research progresses, integrating smart packaging systems with nanosensors may also provide real-time product quality monitoring, creating more sustainable and efficient supply chains.

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Authors' contributions

MK conceptualized and wrote the original draft of the manuscript. AB, KRR, KV and TA did the revision of draft, inclusion of tables and figures, as well as proofreading. AB, KV, TA, RR, CR[1], SM and CR[2] performed the revision, formatting, and supervision. All the authors read and approved the final version of the manuscript. (CR[1] stands for C Ravindran and CR[2] stands for C Rajamanikam)

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We have used only the Chatgpt AI tool to paraphrase a few sentences. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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