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REVIEW ARTICLE

Floral fortification: Post-harvest strategies for enhancing flower longevity

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Abstract

Due to their perishable nature, the floriculture industry faces significant challenges in preserving the freshness and quality of cut flowers post-harvest. Traditional preservation methods are often inadequate for maintaining flowers' aesthetic and biological value during storage and transport. This review explores the innovative application of nanotechnology in extending the shelf life of cut flowers. Nanoparticles, such as silver and zinc oxide, exhibit unique properties that effectively delay senescence and reduce microbial growth. By examining recent advances and case studies, this review highlights how nanomaterials can enhance water uptake, improve resistance to ethylene and maintain turgidity in various floral species. Integrating these nanotechnologies promises to revolutionize post-harvest handling, offering significant improvements in flower quality and economic returns for the floriculture sector.

Keywords

nanoparticles; shelf life; senescence; post-harvest; preservation

Introduction

Nanotechnology is the study of microscopic objects that range in size from 1 to 100 nanometers (one nanometer is one billionth of a meter). Nanotechnology is the technological revolution of the twenty-first century because of its extraordinary structural, morphological, and magnetic characteristics. Although the term "nanotechnology" was used in 1974 by Dr. N. Taniguchi of Tokyo University of Science in Japan, American physicist Dr. Richard Phillips Feynman is credited with inventing the newest science (1).

The application of structure, devices, and systems through size and shape control at the nanoscale is known as nanotechnology. Applied nanotechnology has great potential across all scientific and industrial domains. The primary obstacle to the widespread application of nanotechnology is that nanoparticle properties differ significantly from those of larger-scale applications.

Regarding trade and consumer approval, ornamental crops' post-harvest quality determines their future in the global market. If not handled appropriately after harvesting, produce grown with intense care and control may not always perform well. The perishable nature of flower crops makes them highly vulnerable to oxidative damage after harvest. The ornamental plant business uses more chemical inputs than other industries because numerous post-harvest management techniques are used to ensure quality and maximum profitability.

The high market value of cut flowers has led to significant growth in the production of floricultural crops globally in recent decades, especially in many developing nations, creating a multibillion-dollar global business. The most widely sold floriculture products worldwide include Rose (*Rosa* spp.), Carnation (*Dianthus caryophyllus*), Chrysanthemum (*Chrysanthemum* spp.), Gerbera (*Gerbera* spp.), Gladioli (*Gladiolus* spp.), Gypsophila (*Gypsophila* spp.), Orchid (Orchidaceae), Achilleas (*Achillea* spp.), Anthurium (*Anthurium* spp.), Tulip (*Tulipa* spp.) and Lily (*Lilium* spp.).

Many plant species are being employed in synthesising nickel, cobalt, zinc, copper, gold, silver, etc. The small size of these nanoparticles leads to a high surface area relative to their volume, which enhances their reactivity and interaction with other substances. Their structure, such as shape and crystalline arrangement, can further dictate specific behaviours, such as how they scatter light or interact with biological molecules (2). Nanomaterials are divided into groups based on their structure, size and characteristics. Desirable physiochemical features of such nanoparticles with a high surface volume ratio include solubility, bioavailability, diffusivity, optics, colour, strength, intoxication, magnetism and thermodynamics (3).

Flower Senescence

After being harvested, flowers persist in vitality, sustaining metabolic processes resulting in carbohydrate depletion, elevated temperatures, heightened respiration rates, swift microbial proliferation, water stress, and augmented ethylene accumulation. These collective activities contribute to the degradation of harvested flowers, subsequently reducing the overall lifespan of the fresh produce. This underscores the imperative for suitable post -harvest handling technologies.

The primary factors contributing to the decline of harvested flowers can be categorized as follows -

1) Pre-harvest factors

2) Harvest factors and

3) Post-harvest factors

Post Harvest Factors

A 90-92% relative humidity is recommended for storing cut flowers to maintain turgidity and extend their shelf life. Conditioning involves placing flowers in water with ample air circulation to restore turgidity. Pre-cooling, through methods like hydro cooling or refrigeration, is essential to reduce respiration rates and should occur quickly after harvest, with specific recommended temperatures for different flowers (4)

The regulatory processes governing the senescence of flowers

As specialized and advanced structures, flowers play a crucial role in enhancing the reproductive success of angiosperms, commonly known as flowering plants. In a typical dicotyledonous plant, a flower comprises four distinct organ types: sepals, petals, stamens, and carpels. Petals, among these, serve a primary function in attracting pollinators and facilitating pollination, as highlighted by Glover and Martin (5). While petals hold significance both biologically and aesthetically, they do not directly contribute to the reproductive process, unlike stamens and carpels. A flower's ornamental and economic value is influenced mainly by the process of petal senescence, making it a critical factor for the floral industry.

Flower petals undergo a programmed death process called senescence, which has two types: wilting senescence and abscission senescence. These petals play a role in attracting pollinators but are not directly involved in reproduction. They act as a storage area for nutrients until fertilization occurs. The petals release these nutrients during senescence, becoming a food source for other plant parts. However, the rate of nutrient release in petals is lower than in leaves (6).

As petals age, their internal structure breaks down in a specific way. The cells within the petals contain few chloroplasts, which are replaced by chromoplasts. The petals also have low levels of carbohydrates and other energy or transport compounds. Instead, they contain higher amounts of secondary metabolites, such as anthocyanins, carotenoids and volatile compounds. During petal ageing, sugar levels gradually decrease (7). Petal senescence, like fruit senescence, can be divided into two main types: ethylene-sensitive and ethylene-insensitive (8).

When petals reach the end of their life cycle, they enter a senescence stage. During senescence, the petals change colour, the scent is lost, wilts and eventually falls off (9). In most plants, the petals lose their colour as they age. In roses, the rise in flavonoid and anthocyanin levels during senescence contributes to developing a deep blue petal colour (10). This feature could offer a benefit by extending the flower's allure to pollinators, thus amplifying its attraction to other flowers within the same species.

Ethylene: Key Hormone in Flower Senescence

Ethylene acts as a critical hormone in plants, heavily influencing flower ageing. Numerous studies, including those by (11) and (12), have shown that ethylene accelerates ageing in many plants sensitive to it. In flowers like Petunias and Carnations that respond to ethylene, ageing petals coincide with a surge in ethylene production. This is similar to the feedback loop seen in fruits during ripening, as mentioned in studies (13).

Flower senescence begins with ethylene production from the stigma, activating specific genes known as 1-aminocyclopropane-1-carboxylic acid synthesis (ACS) genes and ACC oxidase (ACO) genes, which further stimulate ethylene production (14).

According to research, ethylene stimulates the RhETR3 and RhCTR genes,which reveals distinct ethylene response and control mechanisms in ethylene-sensitive flowers and accelerates petal ageing (11).This suggests the existence of diverse mechanisms of ethylene response and regulation in flowers sensitive to ethylene. In contrast, ethylene insensitive flowers have not been extensively studied regarding the role of ethylene and further investigations are required to unravel ethylene-independent pathways, as highlighted by (15)

Nanomaterials in Flower Preservation

Silicon nanoparticles

The surface-to-volume ratio property of silica nanoparticles (SiNPs) is highly reactive on nanoparticles. The treatments with SiNPs considerably impacted the hollyhock seedlings' relative water content (16). In the case of *Lisianthus*, silicon delayed chlorophyll deterioration while retaining the overall amount of chlorophyll, which may have contributed to the prolonged vase life of cut flowers (17).

Silver nanoparticles

Silver nanoparticles are among the most often utilized nanoparticles for microbial growth control (bacteria and fungi); they are clusters of silver atoms with a diameter ranging from 1 to 100 nm (18). In addition to their unique chemical and physical characteristics, NS formulations have a high surface area to volume ratio, allowing them to make good contact with microorganisms and making them very efficient as germicides(19).Studies have shown that nanosilver particles have an anti-ethylene agent on cut Asiatic and Oriental lilies (20). Anthurium stem condition and spathe glossiness are also enhanced by SNPs (21).The vase life of lily (22) and tuberose (*Polianthes tuberosa* L.)(23) was increased significantly due to the antimicrobial properties of silver nanoparticles.

Zinc nanoparticles

Zinc nanoparticles have diameters usually between 5 and 100 nm. By enhancing the bacterial barrier's permeability and thereby diminishing its population, the application of capped ZNPs- a surface coating specifically formulated to enhance the stability of metal nanoparticles- as a hydrating solution successfully prevented microbial attacks at the cut ends of gerbera stems. This approach decreased solution turbidity, a parameter indicative of water quality, and sustained stem hydration while promoting sap flow. (24). The post-harvest properties of lisianthus (*Eustoma grandiflorum*) were enhanced by zinc oxide (ZnO) and zinc graphene oxide (ZnO/G). These enhancements included increased water retention rate, elevated turgor pressure in leaves, enhanced flower opening, and preservation of the pedicel's stiffness and green colouration (25).

Magnesium oxide nanoparticles

The US Food and Drug Administration has certified magnesium oxide as a safe substance and described it as an effective antibacterial chemical in the form of an inorganic metal nanoparticle (MgO NP). Inhibiting ethylene production, MgO NP lowers the expression of the genes for ACS (1-aminocyclopropane-1-carboxylic acid synthase) and ACO (1-aminocyclopropane-1-carboxylic acid oxidase) and prevents petal blackening, both of which contribute to the improved petal quality of cut lotus flowers (*Nelumbo nucifera*) (26).

Copper nanoparticles

According to (27), copper nanoparticles (CNPs) exhibit the capability to deactivate chlorophyllase, thereby averting chlorophyll breakdown in Chrysanthemum plants and extending vase life to threefold (12 days) in comparison to control groups (4 days). Concurrently, the nano copper and nano silver blend enhanced the relative fresh weight and solution uptake in cut roses. Moreover, an elevated concentration of nano copper prolonged the vase life of cut roses and carnations by bolstering antioxidant enzyme activity (superoxide dismutase and catalase) and averting xylem blockage caused by microbial infection (28).

Properties of nanoparticles

Anti-bacterial properties

Silver nanoparticles (AgNPs) emerge as promising alternatives to antibiotics, capable of surmounting bacterial resistance. Consequently, it is essential to advance the development of AgNPs as antibacterial agents. Among various prospective nanomaterials, AgNPs stand out for their considerable surface-to-volume ratios and distinctive crystallographic surface structures, underscoring their potential as effective antibacterial agents. SNPs have an antibacterial impact because they cause structural alterations in the bacterial cell membrane, DNA replication failure, the proton motive force dissipation, and ultimately cell death (29). Sondi and Salopek-Sondi's seminal study revealed the antimicrobial efficacy of silver nanoparticles (AgNPs) against *Escherichia coli*. The investigation observed that when *E. coli* cells were exposed to AgNPs, there was a notable accumulation of AgNPs within the cell wall. Additionally, the study documented the formation of characteristic "pits" in the bacterial cell walls, ultimately resulting in cell death (30).

The huge surface area of SNPs makes them more antimicrobial than other compounds containing silver. Both inside the bacterium and on the cell membrane, they cling. Proteins in the bacterial membrane that contain sulfur interact with SNPs, as do phosphorus-containing molecules that resemble DNA (31).

Antifungal properties

At a concentration of 15 mg, silver nanoparticles (AgNPs) displayed effective antifungal activity against a range of phytopathogenic fungi, including *Alternaria alternata, Sclerotinia sclerotiorum, Macrophomina phaseolina, Rhizoctonia solani, Botrytis cinerea* and *Curvularia lunata* (32,33).

Likewise, AgNPs produced by *Bacillus* species demonstrated potent antifungal effects against the plant pathogenic fungus *Fusarium oxysporum* at a concentration of 8 μg/mL. (34). Biologically synthesized AgNPs demonstrated potent antifungal activity against *Bipolaris sorokiniana* by inhibiting conidial germination(35). Remarkably, AgNPs exhibit inhibitory effects against pathogenic fungi affecting both humans and plants and against indoor fungal species. These include *Penicillium* *brevicompactum, Aspergillus fumigatus, Cladosporium cladosporoides, Chaetomium globosum, Stachybotrys chartarum* and *Mortierella alpine*, when cultured on agar media(36).

Antiviral Activity

With viral-mediated diseases on the rise globally, developing antiviral agents is imperative. Understanding the mechanisms underlying the antiviral activity of AgNPs is crucial for antiviral therapy. AgNPs display unique interactions with bacteria and viruses, influenced by their specific size ranges and shapes (37),(38). Exposure to AgNPs for 24 hours reduced the Bean Yellow Mosaic Virus (BYMV) concentration and the percentage of infection and disease severity(39).

SNPs as ethylene biosynthesis inhibitors

The production of ethylene and vascular blockage by air or bacteria are the two main elements that affect how long many cut flowers last in a vase. Flowers open, petals fall, and early demise are regulated by endogenous ethylene (40). The regulation of the ethylene biosynthesis pathway via the enzymes 1-aminocyclopropane-1-carboxylic acid oxidase (ACO) and 1-aminocyclopropane-1-carboxylic acid synthase (ACS) is achieved by the expression of genes encoding these enzymes. Since SNPs emit silver ions that disrupt the ethylene production pathway and slow down senescence-related processes, they extend the vase life of Cosmos (*Cosmos bipinnatus*) (41). Similarly, SNPs are bound to receptor sites to suppress ethylene production, thereby maintaining the vase life of carnations (42).

Future prospects

The application of nanotechnology in floriculture holds promising potential for transforming post-harvest practices and enhancing flower longevity. Future research should focus on developing smart packaging solutions and nanosensors that can actively monitor and maintain optimal environmental conditions, ensuring flowers' extended shelf life and quality. Additionally, advancements in nanocoatings and targeted nutrient delivery systems could further improve the appearance and durability of cut flowers. To fully realize these benefits, addressing safety and environmental concerns associated with nanomaterials is essential. Collaborative efforts between scientists, industry stakeholders, and regulatory bodies will be crucial in establishing guidelines for the safe and sustainable use of nanotechnology in floriculture. By harnessing the unique properties of nanomaterials, the floriculture industry can achieve significant improvements in post-harvest handling, ultimately enhancing economic returns and reducing waste.

Conclusion

In summary, integrating nanotechnology in the post-harvest phase of floriculture presents a transformative approach. By leveraging nanomaterials and advanced techniques, we can address challenges such as preserving flower freshness, reducing spoilage and enhancing overall quality. The potential benefits extend to improved marketability and economic sustainability within the floriculture industry. Continued research and implementation of nanotechnology in this context are essential for sustainable and efficient post-harvest practices in floriculture. However, it is crucial to acknowledge that ongoing study and responsible implementation are necessary to fully unlock the advantages of nanotechnology in optimizing post-harvest processes for floriculture.

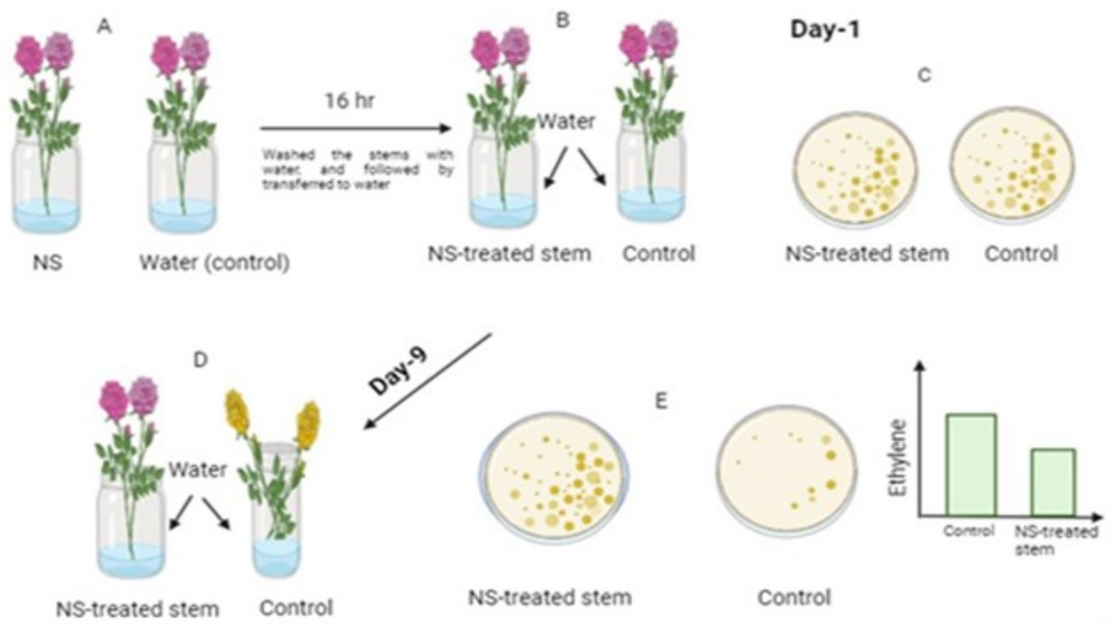

Fig. 1: A schematic diagram illustrating the role of nanosilver in enhancing the post-harvest longevity and quality of cut flowers A: Treatment of immediately harvested cut stems with nano silver particles and distilled water; B: Stage of treated flowers after 24 hrs; C: Status of xylem vessel in cut stem after 24 hrs; D: Stage of flowers after nine days; E: Status of xylem vessels in cut stems after that are blocked with bacteria at day nine after treatment, with higher bacterial blockage in control than NS; F: Graph showing the higher reduction of ethylene content in NS-treated flowers than control. This image is prepared in www.biorender.com

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Authors' contributions

BP collected literature and wrote the manuscript, SK helped in editing, summarizing and revising the final manuscript, CS helped in securing research funds and approving the manuscript, NS helped in summarizing and revising the manuscript, and RP helped in summarizing and revising the manuscript.

Compliance with ethical standards

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