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Review Article

Environmental and consumer friendly approaches for post harvest management of cut flowers

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Abstract

Post Harvest management of flowers utilizing hazardous chemicals is a major ecological challenge across the world. It is essential to understand the cnsequences of different materials and chemicals that provide better vase life to flowers but pose challenges to the environment. Keeping this in view, it is essential to initiate some measures to minimize the production of these wastes as well creating awareness among masses regarding their ill effects on environmental as well as human health. Flowers are not consumed as food and accordingly, many regulatory concerns and potential consequences go unnoticed that may otherwise be alarming for persons associated with production/consumption of flowers across globe. It is, therefore, important to adopt such practices which sound safe and healthy for persons associated with floriculture business. This review summarizes several potential approaches to improve flower vase life with focus on environment and consumer friendly post harvest treatments and preservative components.

Key words: Post harvest, vase life, cut flower, quality preservatives, health

The expressions that cannot be converted in to words can be said, just by offering a single flower as it symbolizes human's expression, spreads beauty, and improves aesthetics. Today global industry represents several categories of ornamental plants and their value-added products that are daily traded worldwide including cut flowers, loose flowers, potted plants, cut foliage and fillers, dried ornamental plants, potpourris, floral colours (gulal), essential oils and flower seeds. Half of the world's production of commercial flower crops comes from Netherlands, United States and Japan where maximum produce is traded through the biggest flower auction centre at Aalsmeer, Netherlands. Countries like Kenya, Colombia, Ecuador and Ethiopia are among the new production centres for flower crops as climatic conditions are more congenial for year-round production at low labour cost. With huge demand of flower crops worldwide to celebrate festive occasions, growers are forced to produce more in less time. Apart from that, quality requirements are very stringent in case of flower crops as their fate is decided by pre and post production processes and subsequent handling. Every production phase in ornamental crops is very strictly regulated to ensure quality after harvest which hugely relies on extensive use of agrochemicals implicating the environmental impact of the industry. End users always want their flower crops to be brightly colourful, fragrant and beautiful in all aspects and to fulfil that, they are often doused with many synthetic chemicals in the production phase of flowers. Additionally, in post harvest phase also flowers are again loaded with many chemicals to maintain their pre-harvest freshness and quality which includes chemicals like acidifying agents (Aluminum sulfate), antimicrobial compounds (8-Hydroxyquinoline citrate, nano silver particles), anti-ethylene compounds (silver thiosulfate), growth regulators (Synthetic gibberellins, Chlormequat) and carbohydrate sources (Sucralose). In a survey conducted in 1977 in Miami, it was found that pesticide

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level in imported flowers ranged from 5 - 400 mg/L (Morse *et al*. 1979). After thirty seven years, another study revealed the same trend and then more studies supported the similar pattern of pesticide usage in flower crops (Toumi *et al*. 2016 a, b). Many active substances were detected in bouquets of cut flowers which are extremely dangerous to work with and could lead to severe health complications. Lack of local regulations with undefined maximum residue limits (MRL) and inadequate certification standards in flower crops are the major contributing factor for excessive use of pesticides and other chemicals in ornamental plant industry (Toumi *et al*. 2017). Some of the important widely used vase chemicals with their environmental hazardous effects are presented in Table 1.

As flowers are not the commodity for consumption as food, so many regulatory concerns and potential consequences go unnoticed which is making situation even graver for persons associated with production and consumption of flower throughout the world. Therefore, it is crucial to adopt those practices which sound safe and healthy for the people involved in flower business.

Following proper hygiene during handling of flowers like wearing gloves and masks is one easy solution to minimize the risk. However, to find a permanent solution to such issues, we need to promote the organic flower production. Our objective for 21st century in ornamental crop cultivation should be to improve the quality without use of excessive chemicals in form of growth regulators or through efficient nutrient management (Raj 2011). Awareness is therefore being raised on combating ill consequences of chemicals and shifting towards the green alternatives by exploitation of plant products as novel therapeutants in flower plants (Gurjar *et al*. 2012). Eco-friendly solutions, which are used as floral preservatives for extending cut flower vase life, have been discovered to be a low-cost and organic alternative as compared to chemical solutions (Nguyen *et al*. 2021). Due to inherent natural antimicrobial properties, plant extracts are now being widely used in vase solutions for improving quality and vase life of cut flowers. However, very limited documented information citing various implications of hazardous chemicals in improving vase life of ornamental plants and scope of ecofriendly treatments such as physical treatment, irradiation, gaseous treatments, and other approaches as a potential alternative is available. In this review, we summarize several potential approaches to improve flower vase life and discuss the best choices for holding-preservative-solution practices in eco friendly way.

Impact of different physical treatments on postharvest life of cut flowers

(a) Heat treatment

Heat treatment is an environmental-friendly technology to extend postharvest life of different products. These treatments have been shown to be effective for disinfestation in red ginger flower (Hara *et al.* 1997). It offers a pathogens-free method and maintains postharvest quality (Francesco *et al*. 2018). These technologies are relatively simple, non-chemical that can kill insects and fungi in perishable commodities, as well as control some post-harvest treatments. Often a cooling process immediately follows a heat treatment to prevent thermal injury of the plant. Two approaches can be considered in developing heat treatments; either warm temperature for long periods or intense heat for short durations (Hallman and Sharp 1990). A promising potential hot water immersion treatment had been developed for cut flowers and foliage. Immersion of non-food perishable commodities such as cut flowers and bulbs in hot water (43.3-48ºC) for 6 min to 1 hour is effective in destroying insect pests while maintaining product quality (Hara *et al*. 1994). Hot water treatment was also effective when applied immediately before placing the flowers in vase water to prevent stem blockage (Bala *et al*. 2006). Hashemabadi *et al.* (2021) examined effect of warm water on postharvest quality of cut rose (*Rosa hybrida* L.). Fresh flowers were treated by water with various temperatures (23°C, 42°C, 47°C, and 52°C) and different time duration (5, 10, 15, and 20 min). They reported that use of warm water (52°C) for 15 min extended vase life (7.52 days) and most traits pertaining to vase life of cut rose as it induces highest water absorption, petals anthocyanin, leafs chlorophyll and lowest ethylene production. Postharvest treatment of red ginger flowers, *Alpinia purpurata* (Vieill.) K. Schume, in hot water at 49°C for 12 min after harvest eliminates most red ginger pests, including aphids, mealybugs, thrips, soft scales and ants (Hara *et al.*

Table: 1 Important chemicals used in preservative solutions with their environmental hazardous effect

S. No.	Chemicals	Role in Post harvest management	Environmental/ health hazards	References
1.	Silver	$AgNO_3$ (10-100 ppm) and Ag-acetate (10-50 ppm) are two most important bactericides used in holding solutions. STS (silver thiosulphate) acts as an inhibitor of ethylene synthesis and respiration.	Silver in used fixer solutions is in the form of silver thiosulphate complexes, which are dissociation constants. There is virtually no free silver ion (Ag+) in used fixer solutions. Waste-water treatment processes convert silver thiosulphate into mostly silver sulfide, which settles in the sludge. The effect of silver on aquatic life depends on the form of silver. In a study using fathead minnows, silver thiosulphate was more than 17,500 times less toxic and silver sulfide was more than 15,000 times less toxic than free silver ion (Ag+). Because of these high silver levels, it is illegal to put used fixer down the drain, into a septic system or into the garbage. The best way to manage silver waste is through recovery and recycling. Silver cation can persist in soil and groundwater, potentially contaminating drinking water and harming aquatic life.	Muhamedagic *et al*. (2009)
2.	Nickel	Acts as germicide, and as an inhibitor of ethylene production, promotes vase life of cut flowers.	Toxicity by nickel: Dermatitis, nausea, chronic asthma, coughing, human carcinogen	Parmar and Thakur (2013)
3.	Cobalt	Cobalt chloride acts as anti ethylene compound, improves longevity and flower quality of cut flowers by inhibiting vascular blockage, closing stomata etc.	The two main target organs of cobalt are the skin and the respiratory tract. Cobalt itself may cause allergic dermatitis, rhinitis and asthma. Cobalt will accumulate in plants and in the bodies of animals that eat these plants, but cobalt is not known to bio magnify up the food chain.	Domingo (1989)
4.	Copper	Acts as germicide, used as an antimicrobial compound	It may be found as a contaminant in food, especially shell fish, liver, mushrooms, nuts and chocolates. Any packaging container using copper material may contaminate food, water and drink and cause neurotoxicity commonly known as "Wilson's disease" due to deposition in the lenticular nucleus of the brain and kidney failure. In some instances, exposure to copper has resulted in jaundice and enlarged liver.	Parmar and Thakur (2013)
5.	Chlorine	Effective bactericide, prolong vase life and improve flower quality.	According to Safe Work Australia, chlorine is classified as a "Hazardous Chemical". It is also classified as "Dangerous Goods" for transport by road or rail. High amounts of chloride are toxic to fish, aquatic organisms, amphibians, and aquatic vegetation.	https://cacgas.com.au/blog/chlorine-gas-hazards/
6.	Quaternary ammonium compound	Physan-20, an effective biocide for conditioning and bud opening of carnations.	The environmental fate and impact of chronic low doses of QACs could cause acute toxicity and lead to antimicrobial resistance. A commonly used quaternary ammonium salt, quaternium 15, is a well-known skin allergen that can cause dermatitis in humans when used in excess (Cahill and Nixon, 2005).	Florists Review (1978)

1996). Tsang *et al.* (1995) reported hot-water treatment (49°C for 12 min) was nonphytotoxic and extended the vase life of red ginger. Postharvest hot water treatments can successfully decrease both incidence and severity of leaf senescence in Asiatic hybrid lilies, as well as delaying its onset. The treatment of cut Lilium flower with hot water (50°C for 5 min or 52.5°C for 2.5 min) effectively increased the vase life and reduced leaf yellowing (Woolf *et al.* 2012). Hamidi *et al.* (2020) reported that hot water treatment is effective in increasing the vase life of cut rose flowers. It has been reported that the vase life of flowers that were exposed to postharvest hot-air conditioning prior to hot water immersion (49°C for 12 min) equaled or outperformed the vase life of flowers treated in hot water immersion only or untreated (Hara *et al*. 1997).

(b) Wax coating

Postharvest treatments with the use of coatings constitute an important tool for maintaining floral quality. When applied to the surface of the plant, it changes their physical properties and helps reduce water loss by modifying gas exchange, may increase vase life. Also, it is easy to use and apply (Pinsetta *et al*. 2019).

The hydroxypropyl methylcellulose compound (HPMC) is a water-soluble cellulose hydrocolloid with good film-forming properties (Sanderson, 1981). Cellulose derivative coatings (HPMC) are formulated specifically to reduce O_2 and CO_2 exchanges (McGuire; Hallman, 1995). Lipid-based coatings are generally used to produce moisture barrier. Among the lipid materials, beeswax is used to improve the water vapor barrier characteristics (Fagundes et *al*. 2013). Use of a coating that associates the characteristics of a material with a barrier to gas exchange, and another with a barrier to humidity, can potentially extend the vase life in cut flowers. Coating with hydroxypropyl methylcellulose and beeswax sprayed at 3.0 mL/rose extended vase life in 2 days and improved the physiological status as it was able to delay the deterioration of the cell membrane affected by plant senescence. Moreover, the coating application is easy and safe for the environment and consumer (Pinsetta *et al*. 2019).

Chitosan is a cationic linear polysaccharide with higher efficiency for encapsulating natural substances. It also has antimicrobial characteristics, which help to prevent postharvest deterioration in horticultural crops (Liu *et al*. 2007). Hong-juan and Huan-qing (2015) reported the effectiveness of the coating of cut roses with chitooligosaccharide (a derivate of chitosan) with increase of vase life by 6.4 days compared with the control treatment. Bañuelos-Hernández *et al*. (2017) studied effects of chitosan coating on vase life of flower stems of *Heliconia bihai* (L.) L. Halloween. Concentrations of 1.0 and 1.5% of chitosan, extended the vase life by 10.3 and 7 days more than the control, respectively. Ka-ipo *et al*. (1989) found that the dipping of *H. psittacorum* cv. Parakeet in Wilt " Pruf® or wax showed 36% increase of vase life. Hajizadeh *et al*. (2023) observed that maximum vase life (15 days) was attained by cut rose cv. Black Magic placed in a preservative solution containing 10 mg L^{-1} CTS-NPs (Chitosan nanoparticles). The CTS-NPs was found to increased antioxidant defense mechanisms, which reduces Hydrogen peroxide (H_2O_2) and Malondialdehyde (MDA) content and preserved membranes integrity at 10 mg/l concentrations. CTS-NPs preservative solutions retained higher, total anthocyanins, total phenolic content, total favonoids and enzymatic activities. Ali *et al*. (2022) studied the effect of 400 mg/m^3 of 1-methylcyclopropene (1-MCP) and either the pre or postharvest application of 1% chitosan nanoparticles (CSNPs) on maintaining the quality of damask rose flowers during storage at 4 or 20 °C. They reported that both treatments preserve the quality and extend the shelf life of damask rose. CSNPs were more effective than 1-MCP.

(c) Irradiation

Radiation is used as one of the phytosanitary treatment to disinfest fresh products, on the condition that the doses used do not damage the product. Madhubala *et al*. (2021) found that Dendrobium var. Sonia was toletant to 450 Gy dose irradiation to control most of the quarantine significance pests and 8-Hydroxy quinoline sulphate (150 ppm) has a great potential to prolong the vase life. Bajpay and Dwivedi (2018) observed that maximum vase life of flower and foliage, maximum diameter of flower, total solution uptake was highest with 1Kr gamma radiation and HQS 200 ppm holding solutions in chrysanthemum flowers cv. Little Pink. Darras *et al.* (2012) reported that Gerbera flowers irradiated with 1.0 or 10.0 kJ m^{-2}

UV-C showed improvement in vase-life by 1.8 and 2.4 days, decrease in stem break percentages by 43 and 29% and delay in stem break incidence by 3.3 and 1.3 days, respectively. Kwon *et al*. (2020) observed that electron beam irradiation doses for 10% reduction of postharvest quality (ED_{10}) values were 144.4, 451.6, and 841.2 Gy in the 'Medusa' lily, 'Montezuma' carnation, and 'Rosina White' eustoma, respectively. Maximum vase lives of 12.00 days were recorded in 3 days treatments with gamma rays 0.025 Gy in combination with pulsing of sucrose (3 %) for 24 h and dry cold storage (2^0C) on vase life of rose cv. Golden Gate (Kumar and Mishra, 2007). Bansiddhi and Siriphontangmun (1999) reported that effective dose for post-harvest controlling of Dendrobium orchid thrips palmi Karny was 0.75 - 0.8 kGy.

(d) Antimicrobial agents

Natural antimicrobials can be obtained from plants, animals, bacteria, algae and fungi etc. Antimicrobial activity of plant extracts may be due to presence of phenolic compounds or other hydrophobic components in the essential oils (EOs) (Dorman & Deans 2000). Anti-browning agents that function as reducing agents and enzyme inhibitors are effective to curb the browning reactions in the fresh-cut commodity (Kumar *et al*. 2018).

Abdoli *et al*. (2022) reported that the highest vase life (13.66 days) was obtained in 25 and 50 ppm of distilled water *Citrus aurantifolia* peel extracts treatments in lisianthus (*Eustoma grandiflorum*). Fatima *et al.* (2022) conducted two experiments using different folk preservatives viz. citric acid, lime juice, aloe vera gel, moringa leaf extract (MLE), bleach etc. as pulsing treatments and found that 2% sucrose + 150 mg L^{-1} citric acid had longest vase life (10.3 days) whereas in next experiment, vase treatments was compared with commercial solutions, Floralife Clear Professional Flower Food, Chrysal Clear Universal Flower Food and 2% sucrose + 4 mL L^{-1} lime juice had longest vase life (16.6, 15.9 and 15.7 days, respectively) and were statistically similar, use of sugar with lemon/lime juice as a vase solution produced a similar vase life (15.7 days) as commercial preservatives in lisianthus (*Eustoma grandiflorum*). Hassan and Fetouh (2019) found that 3% moringa leaf extract (MLE) have preservative effect in improving the longevity and postharvest quality of gladiolus. Kavosiv *et al*. (2013) reported that Thyme oil as antimicrobial agents in preservative solutions is effective in minimizing bacterial growth and development while extending vase life in cut *Rosa hybrida* cv. White Naomi.

For maintaining gerbera cut flowers quality and vase life, *Zataria multiflora* essential oil (200 mg/ L) and *Ferula assafoetida* essential oil (100 mg/ L) were the best (Mallahi *et al*. 2018). Kilic *et al*. (2019) reported that plant extracts like sage (*Salvia officinalis* @ 50 µL/100 mL) and balm (*Melissa officinalis* @ 100 µL/100 mL) give longest vase life in gerbera cv. Rosalin. Parween and Gupta (2022) found that combination of Thymus oil 5 mg/l+ citric acid 300 ppm + sucrose 4% were most effective treatments for enhancement of post harvest quality attributes of cut gerbera cv Stanza. Mohammadi *et al*. (2020) observed that 1.5 and 2% Tashenehdari extract (*Scrophularia striata* Boiss) was useful in vase life improvement in 'Stanza' and 'Pink Elegance' gerbera flowers. Shokalu *et al*. (2018) reported that quality and vase life of cut *Heliconia* 'Golden Torch' flowers was extended significantly beyond 14 days with *Aloe vera* at 5.0% with 4% sucrose. Khenizy *et al*. (2014) reported that natural extracts like thyme (25%) + sucrose (2%) + salicylic acid (150 mg/l) and moringa (25%) + sucrose (2%) + salicylic acid (150 mg/l) significantly improved vase life of gypsophila flowers. For improving quality parameters and vase life of cut tuberose (*Polianthes tuberosa* L.) peppermint oil (150 and 200) mg/l, thyme oil (75 and 100) mg/l, black cumin oil (100 mg/l), rosemary oil (200 mg/l) and salicylic acid (50, 100 and 150) mg/l were found effective (Ezz *et al*. 2018). Hashemi *et al*. (2013) suggessted preservative solutions containing 125 mg L^{-1} thymol and 4% Sucrose at 3±1ºC and 75-80% RH for chrysanthemum.

(e) Salicylic acid

SA is a phenolic compound that inhibits ethylene production, the inhibitory actions of SA most closely resembled with that of dinitro phenol, a known inhibitor of ethylene forming enzyme (Leslie and Romani, 1988). Hatamzadeh *et al*. (2012) assessed the effect of salicylic acid (SA) on the quality and vase life of cut Gladiolus cv. Wings Sensation flowers over four developmental stages (bud stage; half bloom; full bloom; senescence). Flowers were treated in different concentrations of SA (50, 100, 150 and 200 mg/L) and found that the SA delayed flower senescence and leakage of ion in petals, as well as decreased fresh weight loss and lipid peroxidation. In tuberose cultivars 'Vaibhav' and 'Mexican Single', 100 ppm salicylic acid along with 4% sucrose was found best in extending the vase life (Kumari *et al.* 2014). Roodbaraky and Roodbaraky *et al*. (2012) studied the effect of salicylic acid on vase life and postharvest quality of cut carnation (*Dianthus caryophyllus* L. 'Liberty Abgr'). Application of 150 mg/l salicylic acid had the priority in 3 traits: 12.67 days vase life, 48.17 $log_{10}CFUml^{-1}$ bacterial clonies and 12.86% dry matter percent while in case of control 10.62 days vase life, 94.67 $log_{10}CFUml^{-1}$ bacterial clonies and 8.68% dry matter percent were found. Application of 50 mg/l salicylic acid had the maximum water uptake. Singh *et al*. (2018) worked on salicylic acid and nitric oxide on postharvest quality and senescence of gerbera and found that dipping of gerbera in 2 mM salicylic acid vase solution is beneficial in extending its vase life.

(f) Nitric oxide

NO was first characterised in plants in 1996 (Leshem and Haramaty, 1996) and subsequent investigations have linked its occurrence to a range of physiological processes including modulation of endogenous ethylene and vegetative stress (Leshem and Pinchasov 2000), water loss (Ku *et al*. 2000), plant immunity (Hausladen and Stamler 1998), anthocyanin biosynthesis and chlorophyll production (Giba *et al*. 1998), root growth and fruit and flower formation (Lamattina *et al.* 2001). Postharvest application of NO has been shown to be effective in extending the postharvest life of a range of flowers, fruits and vegetables when applied as a short-term fumigation treatment at low concentrations (Wills *et al*. 2000). In gladiolus, 100 mg/ L SNP (sodium nitroprusside) as a holding solution improved the postharvest quality by influencing biochemical and physiological attributes (Mittal *et al*. 2021). Badiyan *et al*. (2004) reported that with the use of NO donor compound 2,2' -(hydroxynitrosohydrazino)-bisethanamine (DETA/NO) at 10 mg/l, vase life was extended upto 40% in Snapdragon (*Antirrhinum majus* L. 'Chitchat'), 40% in delphinium (*Delphinium ajacis* L. 'Bellisimo'), 10% in chrysanthemum (*Dendranthema grandiflora* RAM. 'Regan'), 50% in tulip (*Tulipa hybrid* 'Golden Brush'), 200% in gerbera (*Gerbera jamesonii* H. Bolus 'Manovale'), 40% in oriental lily (*Lilium asiaticum* L. 'Specisiom Simplon'), 20% in rose (*Rosa hybrid* L. 'Carnavale') and 50% in iris (*Iris hollandica* Tub. 'Blue Magic') cut flowers. Liao *et al*. (2013) reported that treatments with 200 μM of SNP (sodium nitroprusside) for 24 hours obtained maximum vase life and flower diameter in cut rose (*Rosa hybrida* L. 'Kardinal'). Nitric oxide may function as a signal molecule involved in the senescence of cut rose regulated by ethylene. In rose cv. Sensiro, 40 μM L^{-1} SNP increased water relative content, flower diameter and vase life (Sharafi *et al*. 2013). Zeng *et al.* (2011) reported that vase life of cut carnation flowers was markedly extended by 0.1 mmol L^{-1} sodium nitroprussiate SNP treatment.

Ashouri Vajari and Nalousi (2015) reported that exogenous nitric oxide significantly extends vase life of cut carnation flowers (16.9 days) as they delay petal wilting, maintaining water metabolism, the antioxidative enzymes activity and mass-eliminate reactive oxygen species (ROS) as well as cell membrane stability. Dwivedi *et al.* (2016) observed that vase solution having SNP (100 ppm L^{-1}) proved significant increment in cumulative uptake by flower spikes and improved vase life in Gladiolus 'Snow Princess'. Exogenous SNP (150 μM) prolongs vase life via maintaining protein degrade, scavenging free radical in term of anthocyanin and enzymes antioxidant, decreasing polyphenol oxidase, inhibiting lipid peroxidation and improving membrane stability in *Gladiolus grandiflorus* cv. White Prosperity (Kazemzadeh-Beneh *et al*. 2018). Vase life of cut lilium hybrid cv. Eyeliner was markedly extended by SNP treatment (Dhiman and Chander 2013). 25 μmole L^{-1} thidiazuron with 50 μmole L^{-1} sodium nitroprusside was best to extend vase life of lilium (Kaviani and Mortazavi 2013).

Shabanian *et al*. (2018) reported that 150 μM sodium nitroprusside (SNP) extended the vase life of gerbera cut flowers Bayadère and Sunway. Leshem *et al*. (2001) reported that exogenous application of nitric oxide gas either by direct fumigation in an O^{2-} free atmosphere or by means of nitric oxide-releasing chemicals, markedly delays senescence and maturation of freshly cut or picked produce. Zhang *et al*. (2018) reported that calcium ion (Ca^{2+})/calmodulin (CaM) may function as downstream molecules in nitric oxide NO- regulated senescence of cut flowers. SNP (sodium nitroprusside) plays a critical role to prolong vase life by 16 days with preharvest application of 100 µM SNP + 50 µM SNP as pulsing in 'Orange Queen' of Alstroemeria (Sadeghi and Jabbarzadeh 2024). Seyf *et al*. (2012) reported that SNP (50 µMolar) increased vase life of cut rose 'Utopia' from 11 days (control) to 13.3 days. Mortazavi *et al*. (2011) observed that TDZ (thidiazuron) at 40 $\mu Mol.L^{-1}$ concentration with 40 $\mu M.L^{-1}$ SNP decreased ethylene production and senescence of rose by decreasing ethylene output, inhibiting ACC synthase activity, and reducing ACC content. Naing *et al*. (2017) suggested that 10 mg L^{-1} SNP plays a crucial role in multiple modes of action that are associated with the longevity of cut carnation flowers. Huo *et al*. (2018) suggested that both hydrogen gas (H_2) and nitric oxide (NO) could enhance the postharvest freshness of cut flowers. 1% hydrogen-rich water (HRW) and 150 µM sodium nitroprusside (SNP) significantly extended the vase life and quality of lilies. NO might be involved in H_2-improved freshness of cut lilies. Lone *et al*. (2021) suggested that 100 µM SNP effectively curtails neck bending and mitigates senescence in isolated flowers of *Calendula officinalis*.

(g) Ozone

Ozone, an anti-microbial agent, has been widely used in various applications (food preservation, disinfection of biosafety cabinets and treatment of drinking water and sewage) due to its strong oxidizing power. When decomposing in water, ozone decay into diatomic oxygen and free radicals like hydroxyl, hydroperoxyl, superoxide. These free radicles react readily with all inorganic and organic compounds in a solution. Aqueous ozone is preferably used over other oxidizing agents such as chlorine because of its short half-life (a few seconds to hours) and low probability of forming toxic by-products. Rose (*Rosa hybrida*) cut stem placed in aqueous ozone had a three-fold increase in vase life due to the highest xylem vessel activity, CO_2 assimilation rate and stomatal conductance (Robinson *et al*. 2009).

Chung *et al*. (2022) reported that 20% ozone nanobubble (O_3NB) in the vase solution resulted in the highest water uptake and relative fresh weight with lowest senescence rate retaining the vivid color in cut *Cymbidium* 'Spring Pearl'. Almasi *et al*. (2015) reported that pre-treatment of orchid flowers with 300 nL L^{-1} 1-MCP, followed by 5.2 mg L^{-1} aqueous ozone as the vase solution could be recommended to maintain quality and extend vase life of Dendrobium 'Darrenn Glory' and Mokara 'Calypso Jumbo' hybrids. Kim *et al*. (2005) reported that 30 min ozone water treatment was effective for cut flower duration and flower diameter in *Dendranthema grandiflorum* 'Baegkwang'.

(h) 1-MCP

In 1995, a novel ethylene-perception inhibitor named 1-methylcyclopropene (1-MCP) was discovered as potentially successful for the inhibition of ethylene perception in cut flowers and fruits as it is a nontoxic cyclic olefin that competes with ethylene for available binding sites (Sisler *et al*. 1996). In addition, inhibition of ethylene perception and flower senescence following pollination was observed in cut orchids pretreated with 1-MCP (Heyes and Johnston, 1998). In 2000, 1-MCP became available for commercial use and was sold under the trade names of EthylBlocTM (for ornamental plants) and SmartFreshTM (for edible products) (AgroFresh Solutions, Philadelphia, PA, USA). Even in an ethylene-sensitive species such as carnation, low concentrations of 1-MCP were found to be effective in preventing ethylene responses (Sisler and Serek 2003). Compared with STS, 1-MCP not only inhibits ethylene perception but it is also environmentally safer; therefore, its use for the maintenance of postharvest flower quality and longevity of a wide range of cut flower crops has greatly increased. Ha *et al*. (2020) revealed that a simultaneous inhibition of ethylene binding and synthesis using 1-MCP and aminoethoxyvinylglycine (AVG), suppressed plant responses to ethylene and consequently extended the vase life for cut rose in both ethylene-sensitive and ethylene-insensitive cultivars.

Hassan and Ali (2014) examined the effect of 1-MCP or salicylic acid (SA) on the postharvest quality and senescence of gladiolus. Both 1-MCP or SA were able to prolong the vase life and delay floret senescence by regulating the flower water content, maintaining chlorophyll and membrane stability, decreasing ethylene production and lipid peroxidation, and increasing antioxidant enzyme activities. 1-MCP delayed flower senescence as antioxidant.

Ranjbar and Ahmadi (2015) evaluated 1-MCP and ethylene on the antioxidant enzyme activity and vase-life of cut carnation cv. Fortune and found that 1-MCP (1.5 µl/l) improved and delayed the onset of senescence symptoms resulted in extending the vase life. In Alstroemeria cv. Ajax, 500 ppb 1-MCP was best for vase life enhancement (Galati *et al*. 2017). Hongpakdee *et al*. (2022) reported that 50 ppm $Ca(ClO)_2$ in vase solution and 1-MCP as fumigation was effective in maintaining the postharvest quality of 'Shimmer' cut gerbera. Demircioglu *et al*. (2018) found that the Rosa hybrida 'First Red' can be stored for 21 days at 4°C and 70% relative humidity in the solution of 1% sucrose treated with 100 and 200 nL L^{-1} doses of 1-MCP 6 hours at 20°C in 1 m^3 chambers. Almasi *et al*. (2015) suggested that pre-treatment of cut orchid with 300 nL L^{-1} 1-MCP, followed by 5.2 mg L^{-1} aqueous ozone as vase solution to maintain quality and extend vase life of Dendrobium 'Darrenn Glory' and Mokara 'Calypso Jumbo' orchid hybrids. In Dendrobium Sonia Orchid, 0.2 µL L^{-1} 1-MCP for 6 hours gave a vase life of 32 days (Le *et al*. 2018). Chuchoisuwan *et al*. (2019) reported that 0.5 µL L^{-1} 1-MCP for 3 hours had the ability to stimulate certain antioxidant enzymes via the ascorbate-glutathione cycle to retard senescence in Dendrobium 'Khao Sanan'. 1-MCP extended vase life of White Crane Orchid (*Calanthe triplicata*) inflorescences from 6 days to 8 days (Tsai *et al*. 2021). Azlin *et al*. (2013) reported that Mokara 'Oriental Red' and 'Chao Praya Pink' cut orchids respond well to 1-MCP pre-treatment in extending vase life. 1-MCP (500-2000 nl L^{-1}) prevented flower and bud abscission during vase life of cut Dendrobium 'Burana Jade' (Yoodee and Obsuwan 2013). Ketsa and Uthaichay (2012) reported that pretreatment of orchid Dendrobium Jacky with 300 or 500 nl L^{-1} 1-MCP at 25°C for 4 hours can be commercially applied for export purpose. Sapbua *et al*. (2013) reported that 200 nl L^{-1} 1-MCP gave better results in delaying the decreased fresh weight, respiration rate and ethylene production and wilting of flowers as well as bud openings in Dendrobium, 'Red Sonia'.

Kumari *et al*. (2016) reported that 5 mg/l Amino-oxyacetic acid and low concentration of 1-MCP lowered the ethylene production in chrysanthemum cv. Reagan White. 1-MCP (0.9 µL L^{-1}) at 20°C for 16 hours significantly delayed senescence, reduced wilting and abscission in rose, gerbera and carnation flowers (Song *et al*. 2015). Cavasini *et al.* (2015) reported that pre-exposure of 1-MCP for 24 hours increased the durability of the Lisianthus stems with less symptoms of bent neck and swelling of stems. Miller (2014) found that lily flowers generally have low sensitivity to ethylene, after petal expansion but as developing buds they are usually highly sensitive to ethylene. By protecting young, sensitive buds, 1-MCP (1-methylcyclo-propene) can play an important role in maximizing lily display life especially in exogenous ethylene contamination. 1-MCP increased vase life in hybrid cut lilies 'Red Alert' and 'Renoir' (Locke *et al*. 2017). Wu *et al.* (2013) observed that cut flowers treated with 1-MCP packaging and storage at 5°C for 7 days effectively increase the vase life of Oriental cut 'Activa' lily flowers

In *et al*. (2013) reported that 1-MCP binds to ethylene receptors, blocking ethylene binding, thereby represses ethylene responses, including flower senescence and petal abscission. Multiple treatments with 1-MCP completely suppressed several ethylene biosynthesis genes along with ethylene production and increased vase life by almost three-fold in carnations.

Shimizu-Yumoto and Kazuo (2013) observed that dahlia flower senescence is partially regulated by ethylene and 6-benzylaminopurine (BA) is more effective in delaying the senescence of cut dahlia cultivars Kokucho, Kamakura and Michan than ethylene action inhibitors. 1-methylcyclopropene inhibited petal abscission and delayed petal wilting in Dahlia (Azuma *et al*. 2020). Seglie *et al*. (2013) reported that β-Cyclodextrin-based nanosponges proved to enhance 1-MCP efficacy in *Anemone coronaria* L. multicolor, *Ranunculus asiaticus* L. 'Minou Abrown', *Helianthus annuus* L. 'Sunrich Orange', *Rosa hybrida* L. 'Jupiter', *Paeonia lactiflora* L. 'Sarah Bernhardt' and *Papaver nudicaule* L. multicolor. This study opens possibilities for commercial use of the β-CD-NS complex in the floriculture industry.

Conclusion

Nowadays, there is a growing concern to reduce the use of harmful chemicals in flower crops. Noxious chemicals may be replaced with irradiation treatments, wax coating, use of antimicrobial agents, salicylic acid and their derivatives, nitric oxide, ozone, 1-MCP *etc.* for use in vases as post harvest treatments for ornamental crops. Toxic chemicals such as silver derivatives, nickel, cobalt, copper, chlorine, quaternary ammonium compounds, Thiabendazole *etc.* during post harvest handling of flower crops should be curtail to avert associated health effects. Safe and effective natural substitutes need to be investigated for use in vases to reinstate these chemicals.

Future Prospects

Research aimed at enlarging the gamut of post harvest treatments and preservative solutions for cut flowers must be continuing with eco-friendly and natural way. Studies on standardization of different treatments for individual flower crop need to be studied as very meagre work has been done on these aspects.

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