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Review

Do Eco-Friendly Floral Preservative Solutions Prolong Vase Life Better than Chemical Solutions?

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Abstract: Cut flowers have become an export income in the global floriculture market. They have multiple uses, such as for home beautification, in ceremonies (including weddings and funerals), and as symbols of love, appreciation, respect, etc., in humane society. Each type of cut flower has a different vase life and the longevity of their freshness is linked to preharvest, harvest, and postharvest tools and conditions. The postharvest quality and vase life must be considered in order to obtain the desirable qualities of cut flowers, and factors that affect this are important in the floral industry. The use of floral preservative solutions is good practice for prolonging the vase life of cut flowers. Currently, the 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. However, there are certain problems associated with the use of chemical and eco-friendly solutions. In this review, we summarize several potential approaches to improve flower vase life and discuss the best choices for holding-preservative-solution practices.

Keywords: cut flower; floral postharvest storage; flower industry; flower longevity; postharvest quality; postharvest technique

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1. Introduction

The vase life of cut flowers can be characterized as the extended survival of cut flowers in a vase, which is affected by preharvest and postharvest conditions. The floral market is recognized as a global market that links countries together, and the time for exporting is willing reduced by a few days or within a week. The fresh condition of cut flowers is maintained by the use of a preservative solution, postharvest, to provide fresh flowers with a long vase life to the final customer. Each type of cut flower has a particular vase life: the short vase life group (less than 5 days) includes dahlia [1], iris [2], daffodils [3], delphinium [4], and alstroemeria [5]; the medium vase life group (6~14 days), such as protea [6], gladiolus [7], ginger [8], primrose [9], heliconia [10], marigolds [11], snapdragons [12], orchids [13], and rose [14]; and the long vase life group (2 weeks~4 weeks), such as tulips [15], anthuriums [16], carnations [17], and chrysanthemums [18].

As flowers are the symbols of spectacular attention in nature, they endure a lot of different types of postharvest damage, such as dehydrated cause injury, insufficient temperature changes, fungi (*Botrytis cinerea*), mechanical impairment, and bacterial attachment that affect the fresh quality of the arrangement and its vase life [1–6]. The beneficial method for extending the long vase life of cut flowers is being studied. Suitable handling, eco-friendly for a safe environment, non-harmful, and low price are mecessary because poor postharvest practices affect quality losses in cut flowers [19–22]. The most common symptoms are wilting senescence, which is linked to the loss of cell turgor pressure by a failure of water uptake due to stem blockage by air; microbial growth; and physiological plugging [23–25]. Additionally, leaf chlorophyll and petal pigments, such as anthocyanin, carotenoids, and betalains, decline, causing color fading, missing, or breakdown [26–30]. During senescence, the increasing activity of proteases is contrary to the decrease in total protein by rapid proteolysis [31–33]. Moreover, the levels of various lipids decrease, which is linked to cut flower senescence [34–38]. Cellular activities, such as increased respiration and enzymatic hydrolysis, are two processes that occur during senescence in cut flowers [39–41]. Thus, the findings of in-depth studies on postharvest senescence physiology must be applied and optimized to improve cut flower vase life. In addition, various techniques have been used to reduce postharvest disorders and extend the vase life of cut flowers to provide high value for floriculture producers. In this review, we extend the recommendations by considering and summarizing several approach factors that are affected by postharvest quality to improve vase life. We also give information on eco-friendly solutions and provide an opinion on the best application of the preservative solution to extend flower vase life.

2. The Approach Factors for Floral Preservative Solutions

Preharvest factors, including growing conditions or genetic quality, affect floral vase life, which is also linked to postharvest conditions [42–46]. Floral preservative solutions have generally become the best choice for growers, wholesalers, retailers, and customers in the floral industry to prolong vase life and control the quality of cut flowers [47]. Preservative solutions are commonly efficient in many ways, such as inactivating physiological processes, reducing senescence and transpiration, preventing the effects of ethylene, developing petal color, increasing bud and flower opening, preventing bacterial growth, and enhancing water uptake [14,47,48]. Preservative solutions are derived from a mixture of sugars, germicides or biocides, salts, and growth regulators. They increase water uptake by acidifying solutions, reduce microbial growth, and contribute carbohydrates required for the metabolic activities of cut flowers [47–49]. Currently, environmentally-friendly preservative solutions are being developed using eco-friendly powders from plants [47]. In this review, we separate two kinds of floral preservative solutions: chemical and eco-friendly. There are three preservative treatments that can be practiced for prolonging cut flower vase life: bud opening, pulsing, and holding solutions.

2.1. Chemical Preservative Solution

2.1.1. Bud Opening Development

In bud opening development using a preservative solution, growers harvest the buds at an early stage of development and hold them in a solution containing sucrose, plant hormones, and germicides before the opening of the immature buds. Previous studies have shown that low sugar concentrations are considered effective for bud opening of lily [50], chrysanthemums [51], carnation [52], rose [53], snapdragon [54], and gladiolus flowers [55]. Furthermore, the floral postharvest life is extended by checking for low temperature, humidity, and ethylene in shipment spaces [47,56,57].

2.1.2. Pulsing Treatment

Pulsing involves treating the flowers or buds for 16–20 h with higher concentrations of sucrose [55,58–60]. Each species or cultivar responds differently to the sucrose concentration [55]. Chemical pulsing treatments include silver thiosulfate (STS) [18,61,62], hydroquinone (HQ) [34,58,63], 8-hydroxyquinoline sulfate (8-HQS) [39], silver nitrate ($AgNO_3$) [64], aminooxyacetic acid (AOA) [65,66], calcium dichloride ($CaCl_2$) [67], cobalt chloride ($CoCl_2$) [60], aluminum sulphate ($Al_2(SO_4)_3$) [68], chlorine dioxide (ClO_2) [69], and benzyladenine ($C_{12}H_{11}N_5$) [70,71]. High concentrations of silver nitrate solution have been used in studies on the pulsing treatment of many cut flowers, including gerbera [72], gladiolus [73], chrysanthemum [74], carnation [74,75], Persian buttercup [64], herbaceous peony [63], and rose [76]. This pulsing step is necessary for a prolonged storage period or for export outside the country. Moreover, pulsing treatment can improve flower life, promote flower opening, and recover flower size and petal color by controlling osmotic regulation [55].

2.1.3. Holding Solutions (Vase Solutions)

Holding solutions, which contain a combination of carbohydrates (usually sugar), plant growth regulators, germicides, ethylene inhibitors, mineral salts, and organic acids are used to extend the vase life of cut flowers [55,77]. Each flower species and cultivar is adapted to various constituents and concentrations in the holding solution [55,78]. The sugar provides energy for plant respiration, and the germicides affect and kill harmful bacteria, and its action prevents plant tissue plugging [49,79].

2.1.4. Sugar

Sugar is the gold key of floral energy sources as it has positive effects on many physiological activities and metabolic reactions, including bud opening, flower size increase, flower color production, vase life extension, inhibition of ethylene synthesis, and control of water uptake [55,80,81]. There are many studies on sugar solutions for improving flower vase life, and effective sugar concentrations differ for different species [12,34,82]. Respiration is an important metabolic process in cut flowers and is linked to stored starch and sugar reserves for respiration during postharvest life [60,83]. The application of exogenous soluble sugars, such as sucrose, glucose, or fructose in solutions can be used as the energy for extending flower vase life [84,85]. The gradients of sugar concentration were studied and depended on the level of sugar concentration in floral preservative treatments. A high sugar concentration is used for the pulsing treatment, a medium sugar concentration is used for bud opening, and a low concentration of sugar is usually used for vase holding solutions [12,83]. Sucrose is the most frequently used form of sugar to prolong the vase life of cut flowers, and is correlated with the water balance [48,55,81,83,86]. Sugars are also known as osmotically active molecular structures that improve water relations and make turgid hydrolyzed sugars [39,81,85,87]. It can increase the thickness and lignification of the vascular tissues of cut flowers [88]. Moreover, sucrose can affect stomatal closure and reduce water loss [89]. Ichimura et al. (1998) identified that sucrose affects anthocyanin expression by influencing the gene expression for the biosynthesis of anthocyanin [81]. In contrast to these positive effects, sucrose can be linked to the effect of abscisic acid (ABA), which increases senescence [90,91].

2.1.5. Germicides or Biocides

Germicides or biocides are economically available antimicrobial chemicals that are intended to block the growth of bacteria, fungi, and some microorganisms that are present in flower vases [92–96]. Bent-neck symptoms occur when the floral xylem is attacked by bacteria or fungi, which block water uptake, resulting in a short flower vase life [92,97]. As indicated in previous studies, the number of bacteria and fungi in the vase water is related to the vase life of cut flowers [47,55,98,99]. The hydraulic conductivity of flower stems decreases with the number of bacteria per cut flower stem fresh weight [100–102]. A number of germicide solutions have been used to extend the vase life of cut flowers, including the silver compounds: STS [12,103] and $AgNO_3$ [103]); chlorine compounds (sodium hypochlorite, sodium dichloroisocyanurate, and ClO_2 [5]), and certain other compounds, such as 8-HQS [12], 8-Hydroxyquinoline citrate (8-HQC) [104], salicylic acid (SA) [105], calcium [106], calcium nitrate [107], aluminum sulfate [108,109], isothiazolinone [49], and quaternary ammonium chloride [110]). To prevent microbial growth, a sugar solution is always added to a biocide solution [78]. In cut flower roses, germicide treatments preserve the hydraulic conductance of the cut flower stems [92]. Aluminum sulfate solution decreases microbial growth, prevents bacterial growth, increases water uptake, delays senescence, and extends the vase life of cut rose, eustoma, and gladiolus flowers [111]. In a study on lisianthus 'Mariachi Bleu Fonce' cut flowers, the combination of preservative solutions with sucrose, citric acid, and aluminum sulfate extended vase life for more than 13 days compared to that of a water control [82]. In a study on *Rosa hybrida* L. 'Beast' cut flowers, an investigation into the antimicrobial effect of a ClO_2 holding solution containing 2% sugar showed that the combination of solutions extends the postharvest vase life of the cut roses [112]. 8-Hydroxyquinoline salts prevent bacterial growth, delay senescence, and reduce water uptake in gerbera flowers [83,92]. Silver thiosulfate and 8-HQC are usually used as the most effective biocides and are the most active inhibitors of ethylene production [12,83]. Some cut flowers are familiar with STS solutions such as carnation, orchids, gypsophila, gladiolus, gerbera, snapdragon, alstromaeria, agapanthus, anemone and sweet pea. In dendrobium and gladiolus cut flowers, 8-HQS is most effective in preventing microbial growth, reducing respiration rate, increasing water uptake, and extending vase life [113]. Nanometer-sized silver particles (NS) are used as an effective solution for extending the vase life of some cut flowers, including carnations, gerberas, acacias, and roses [114]. The volume ratio of NS particles with large surfaces increases their links with microorganisms, thereby preventing the negative effects of microbes in vase solutions [115,116]. The bactericidal properties of NS also have a positive effect on water uptake. In cut flower roses, pulse treatments for 1h with 50 and 100 mg L^{-1} NS solutions showed an increase in vase life and a suppressed reduction in fresh weight during the vase period. In addition, the NS solutions affect the stem hydraulic conductivity, decreasing stomatal conductance. They also delay *Rh-PIP2* aquaporin gene expression [117]. Silver nitrate and nano-silver also inhibit the ethylene hormone [118]. They can reduce microbial attacks and can be effectively applied to various types of cut flowers, including aster, gerbera, gladiolus, tuberose, carnation, chrysanthemum, phalaenopsis, and snapdragon [23]. Preserving solutions containing a combination of silver compounds and 8-HQC or 8-HQS are environmental hazards because they contain heavy metal compounds [49,110]. Isothiazolinone and quaternary ammonium chloride are widely used as they are safe, stable, broad-spectrum, and efficient biocides for inclusion in floral preservative solutions [49,79]. A number of preservative solution compounds, including lime or lime soda, aspirin tablets, and essential plant oils are used as biocides or acidifiers in natural homemade solutions [21,49].

2.2. Eco-Friendly Floral Preservative Solution

In chrysanthemum 'Arctic Queen White' cut flowers, the use of thyme oil (500 mg L^{-1}) or clove oil (250 mg L^{-1}) produces the longest vase life in both seasons, and reduces bacterial growth [21].

In 'Haesal' cut spray roses, Ha et al. (2019) investigated various pretreatment solutions of *Scutellaria baicalensis* Georgi extract (SC) solution, hydrosol solution, and 1% sucrose [48]. The results showed that 300 $\mu L \cdot L^{-1}$ of SC was the most effective preservative solution with some beneficial effects, such as prolonging vase life, inhibiting bacterial growth, improving fresh weight, enhancing water uptake, and improving water balance [48]. In research on the 'Jinny' cut rose cultivar, natural antimicrobial powders from chrysanthemums and plants of the Ranunculaceae have been extracted and considered as alternative preservative solutions in the cut flower industry [119]. In a study on the cut rose 'Sonia', treatment with 20 mg L^{-1} tea-seed saponins significantly prolongs the vase life [120]. In research on the cut rose 'Carola', the effects of green tea extract (GTE) powder at 2.0 g L^{-1} were compared with preservatives such as 2% (w/v) sucrose, 200 mg L^{-1} 8-HQC plus 2% (w/v) sucrose, or 0.2 mM STS in the vase solution. The results showed that the GTE powder treatment at 2.0 g L^{-1} extends the flower vase life and reduces the fresh weight loss, most likely because of the effects of its high antioxidative and antimicrobial properties on cut roses [121].

Studies of homemade floral preservatives on cut 'ABC Blue' lisianthus (*Eustoma grandiflorum*), '*Maryland Plumblossom*' snapdragon (*Antirrhinum majus*), 'Mid Cheerful Yellow' stock (*Matthiola incana*), and 'Deep Red' Benary's zinnia (*Zinnia violacea*) were investigated as a 48-h grower treatment or continuous retailer/consumer application. Solutions containing 500 mL L^{-1} lemon/lime soda or 400 mg L^{-1} citric acid plus 20 g L^{-1} sugar alone exhibit the best postharvest performance of all tested species [49].

A study on gladiolus has shown that a 2% concentration of *Calotropis procera* leaf extract (CPLE) extends the maximum vase life up to 14.5 days, open florets (64%) and RFW (40%) compared to the effects of *Moringa oleifera* leaf extract (MOLE) and *Mentha piperita* leaf extract (MPLE). Therefore, CPLE at 2% appears to be an effective natural preservative to extend the vase life of gladiolus cut spikes [122].

Aloe vera (*Aloe vera barbadensis*) and moringa (*Moringa oleifera* Lam.) solutions were studied and compared with salicylic acid and calcium chloride solutions for prolonging vase life of cut Heliconia 'Golden Torch' flowers [123]. The combination solution of Aloe vera at 5.0% and sucrose 4% showed the best result in water uptake, provided a percentage of maximum increase in open bracts (67.4%), and gave the highest relative water content (RWC) (78.9%) [123].

Piper betle leaf extract (PbLE) was studied for extending vase life and holding quality of cut spike of tuberose [124]. Four treatment solutions including the control as distilled water, 3% sucrose (T1), 3% sucrose + 100 ppm 5-SSA (T2), 3% sucrose + 50 ppm PbLE (T3), were screened. The results showed that PbLE in T3 might have a significant role in inducing antioxidant enzyme systems at the senescence period, decreasing lipid peroxidation, and increasing membrane stability. These results suggest that T3 solution maintains spike freshness and dry weight, enhances antioxidative defense, maintains membrane integrity to delay senescence in cut spike of tuberose [124].

The use of eco-friendly compounds, which were chitosan (25 and 50 mg L^{-1}), thymol (25 and 50 mg L^{-1}), and green silver nanoparticles (25 and 50 mg L^{-1}) with control (distilled water) and sucrose (2%), were studied on the postharvest of the cut carnation "Tabor". The results showed the cut carnation vase life was extended by the inclusion of either 25 or 50 mg L^{-1} chitosan (17 days) or either 50 mg L^{-1} green silver nanoparticles (15.7 days) as compared with control (10 days) [125].

The vase life study of Gladiolus spikes was investigated by moringa leaf extract (MLE) with various concentrations (0, 1, 2, 3, 4%). All MLE concentrations significantly prolonged the vase life and showed the results of 10 days longer using 3% MLE. According to MLE treatment, the floret opening was improved and the weight loss was reduced in cut spikes. MLE 3% showed the effects on the oxidative stress-induced in the cut spike, maintained photosynthetic pigments and water relations. Therefore, MLE 3% should be applied as a potential-promising eco-friendly preservative solution for cut flowers [126].

3. Further Investigations for Handling Eco-Friendly Preservative Solutions in the Flower Industry

Commercial floral preservatives should provide many more benefits: they are reported to extend vase life, improve flower opening, increase water uptake, control fresh weight, retain flower pigment, and decrease ethylene sensitivity [19,55,83]. The handling of eco-friendly preservative solutions for cut flowers will be managed by various factors such as inhibition of bacterial growth, vase life extension, promotion of a positive water balance, improvement in fresh weight, enhancement of water uptake, and inhibition of the action of ethylene. The benefits of eco-friendly preservative solutions include opacity reduction, inhibition of viscid substances in the stem, restriction of disagreeable odor formation in the stem, vase life extension, and a decrease in fungi and bacteria in the vase solution. The drawbacks to the use of eco-friendly preservative solutions are (1) that many cut flower species do not need any nutritional source, or source of carbohydrates, and (2) the lack of available information on the effectiveness of eco-friendly preservative solutions on the postharvest longevity and quality of cut flowers, especially preservatives derived from natural plant substances. To overcome these drawbacks, a new eco-friendly preservative solution should be developed. This should include a combination of sucrose, citric acid, and biocides, which could provide an effective natural preservative because citric acid and biocides control the growth of microorganisms, whereas sucrose mediates the osmotic potential of the cut flowers by blocking the action of ethylene. Another option is the use of powder extracts from natural plants such as Asteraceae species and other plants because these are safe for human health. However, eco-friendly preservative solutions are determined as natural solutions with maintenance limitations. Do eco-friendly preservative solutions prolong vase life better than chemical solutions? The answer to this question requires further research; however, we can look forward to having low cost, friendly with the environment, especially that the eco-friendly preservative solution is not harmful to people and animals in the future (see Figure 1).

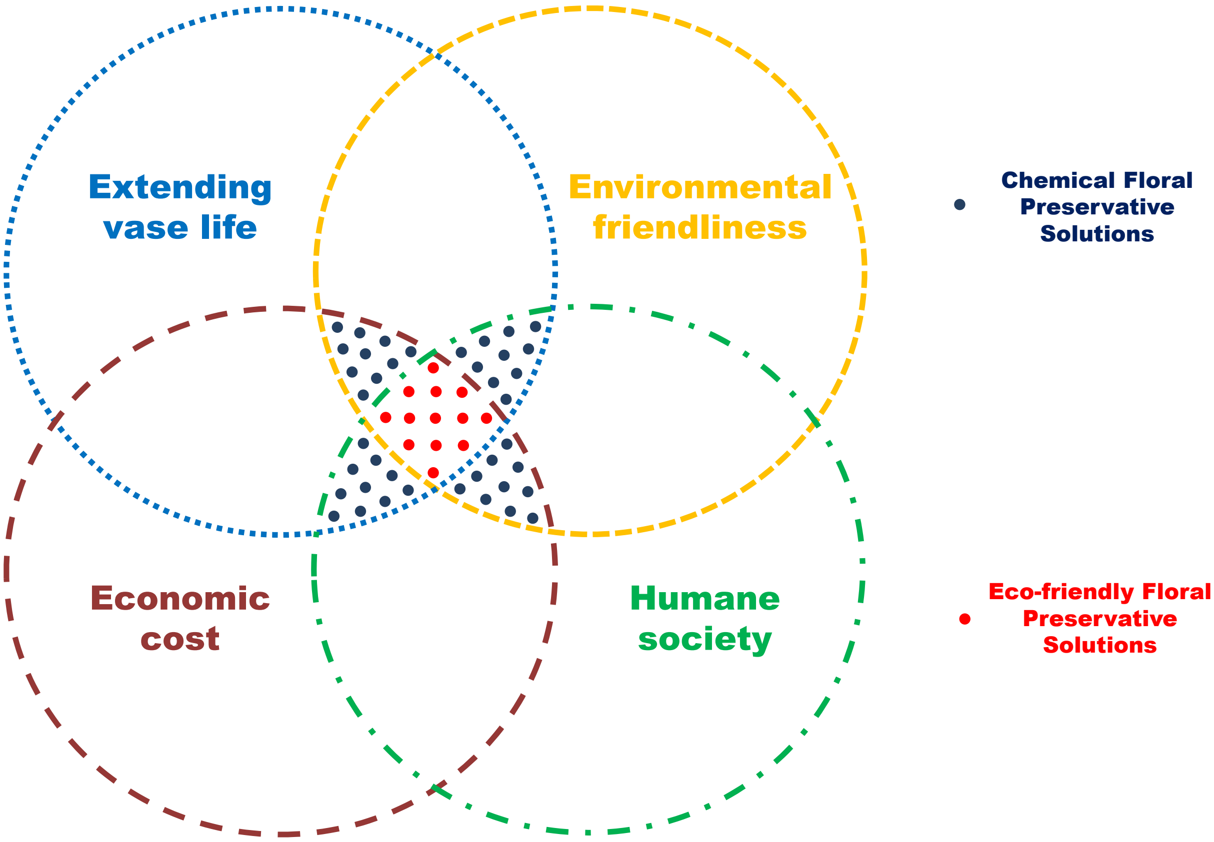

Figure 1. Dimensions of further development of floral preservative solutions.

4. Conclusions

By reviewing the different approaches and factors associated with the use of floral preservative solutions for the development of proper handling in the cut flower industry, we have not only helped florists and scientists to recognize appropriate preservative solutions, but have also provided a synthesis of the considerations associated with promoting the vase life of cut flowers using preservative solutions. Research aimed at expanding the range of preservative solutions for cut flowers must be ongoing, and the development of eco-friendly, natural preservative solutions must be prioritized in the cut flower industry.

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