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| RESEARCH ARTICLE

Review of Recent Advances in Chemical Preservatives for Cut Flowers

Sihan Chen
Institute of Biological and Food Engineering, Guangdong University of Education, Guangzhou China
Corresponding Author: Sihan Chen, **E-mail**: samuel333chen@163.com

| ABSTRACT

Cut flowers is an important part of the floriculture industry, and the changes in their physiological and biochemical status after harvesting can accelerate the aging process, affecting the overall quality of the cut flowers. With the development of the floriculture industry, the increasing variety of cut flowers makes preservation research increasingly important. This paper explores the physiological and biochemical characteristics of the aging of fresh cut flowers, analyzes the changes in water metabolism, macromolecular substance metabolism, cell membrane, and endogenous hormones. It also focuses on the types of chemical preservatives (pre-treatment solutions, flower inducing solutions, and vase solutions), their components (water, saccharides, organic acids, fungicides, plant growth regulators, soluble inorganic salts), and their effects, aiming to provide insights for the development of chemical preservatives for cut flowers.

| KEYWORDS

Cut flowers; Post-harvest senescence; Physiological and biochemical changes; Chemical preservation

| ARTICLE INFORMATION

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1. Introduction

Fresh cut flowers refer to the flowers, flower branches, and leaves that are cut from the plant body and made into floral decorations (Cao & Chen, 2015). In recent years, China's cut flower industry has flourished, not only building a complete flower industry chain, but also becoming home to the largest flower trading market in Asia. At the same time, with abundant floral resources and strong capabilities in breeding new varieties, China has made remarkable achievements in the field of floriculture. China has become an important player in the import and export of flowers, with the total trade volume reaching 710 million US dollars in 2023, and the trade volume of cut flowers accounting for 23.31% of the total flower trade, second only to bulb exports. With the development of the cut flower industry, the variety of cut flowers has become increasingly diverse, making research on the preservation of cut flowers crucial. This article will provide a comprehensive review of the physiological and biochemical changes of fresh cut flowers after harvesting, the types and components of chemical preservatives, and their effects, with the aim of providing a reference for the research and preservation of cut flowers.

2. Post-harvest Physiological Characteristics of Cut flowers

2.1 Water metabolism

The aging of flowers is mainly manifested as petal fading or discoloration, petal dehydration, and loss of fragrance. Only when the amount of water absorbed by the petals reaches a stable equilibrium with the amount of water lost, maintaining a certain degree of turgor pressure, can wilting be effectively prevented. After being detached from the plant, the water balance of fresh-cut flowers is disrupted, and their source of nutrients is cut off, greatly reducing their vase life and accelerating the aging process (Yu et al., 2020). Water balance is an important factor affecting the vase life of cut flowers, and various imbalances in water metabolism are the main reasons for flower aging (Vivian & Roon, 2000). Research has found that improving the water absorption capacity of flowers, alleviating water stress, and promoting water balance can extend the vase life of peonies (Paeonia suffruticosa) (Guo et al., 2005). Li et al. (2013) found that prolonged water deprivation during storage will accelerate flower opening and stem aging, significantly shortening the vase life of chrysanthemum cut flowers. The water status of cut flowers depends on the balance between water absorption, internal translocation, and transpiration. Cutting the stem leads to a decrease in water uptake due to clogging of the stem, leading to an imbalance in water and subsequent flower aging (Shi, 2018). Plant secretions, bacteria and their metabolites, gas plugs in the stem, and large particles at the base of the cut are all major causes of stem clogging (Gu et al., 2020; De Boer & Volkov, 2003; Ma et al., 2008; Xue et al., 2020; Xue et al., 2009; Jedrzejuk et al., 2012). Therefore, maintaining water balance within fresh-cut flower tissues is crucial for extending their vase life.

2.2 Metabolism of Mcromolecules

Saccharides are not only nutrients in organisms but also serve as signaling molecules to regulate plant growth mechanisms (Zhao, 2020). The consumption and metabolism of macromolecular nutrients during the development of fresh-cut flowers lead to insufficient nutrient supply, thus promoting flower aging (Liu et al., 2020). The degradation of starch and pectin, as well as the accumulation of hexose, reduces the turgor pressure of petal cells, promoting water absorption and expansion of petal cells (Hammond, 1982; Bieleski, 1993). In addition, saccharides are beneficial for promoting flower opening, closing of stomata, protecting mitochondrial structure, maintaining membrane integrity and improving the quality of cut flowers (Yang, 2001; Yan., 2021). Supplementation of exogenous saccharides can help flowers maintain normal energy metabolism and reduce ethylene sensitivity, hence sucrose treatment is commonly used to extend the vase life of cut flowers (Kong et al., 2022). Studies have found that saccharides can improve the vase quality of gladiolus (Gladiolus hybridus) and dahlia (Dahlia pinnata) cut flowers (Shi et al., 2008; Xiong et al., 2021). On the other hand, during the early stages of flowering, protein synthesis predominates in petal cells, leading to an increase in protein content. As the flower enters the aging process, the rate of protein synthesis slows down, and proteins gradually degrade, catalyzed by proteases, deoxyribonuclease (DNase), and ribonuclease (RNase) (Ji, 2023). In plants such as tulips (Tulipa gesneriana) and roses, the protein content shows a unimodal curve that initially increases and then decreases during the aging process (Yan et al., 1997; Su, 2021). In the aging process of rose cut flowers, the soluble protein content decreases while the free amino acid content increases (Gao & Wu, 1990).

2.3 Changes in Cell Membrane

During the vase insertion process of fresh cut flowers, proline serves as an efficient osmotic regulator, maintaining cell homeostasis, scavenging reactive oxygen species (ROS), protecting plant organs and cell function integrity, and enhancing the plant adaptability to environmental stress (Song et al., 1992; Xiao et al., 2020). The changes in proline content can reflect the level of water stress experienced by the plant (Blum, 2017). As flowers develop and age, the relative permeability of petal cell membranes changes, leading to an increase in membrane lipid peroxidation, resulting in increased malondialdehyde (MDA) content and relative conductance (Pan, 2001; He, 2021). Additionally, the imbalance between the production and elimination of active oxygen in petals is also an important factor causing flower aging, such as changes in the activity of enzymes like peroxidase (POD), catalase (CAT), and superoxide dismutase (SOD) (He 2021; Peng et al., 2021). During the blooming and aging process of fresh cut flowers, the significant accumulation of malondialdehyde (MDA) in petal cells leads to a continuous increase in cell membrane permeability and exacerbates membrane lipid peroxidation, causing membrane damage (Sarwat & Tuteja, 2019). The greater the cell membrane permeability and aging, the higher the relative conductance (Li et al., 2007). Moreover, when the production and clearance of active oxygen within the cells are imbalanced, oxidative stress occurs. The accumulation of active oxygen can damage the cell membrane structure, functional proteins, and nucleic acids, accelerating the aging process (Hu et al., 2023). Therefore, the balance of active oxygen is closely related to flower aging. Plant cells have a sophisticated system for clearing active oxygen, including protective enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) (Hu et al., 2018; Song et al., 1992; Rhodes et al., 1989). In the early stages of flower aging, the activity of these protective enzymes initially increases and then decreases as the aging process intensifies (Cheng, 2009).

2.4 Changes in Endogenous

The aging process of plants is accompanied by changes in the levels of plant hormones. Plant hormones are active substances that induce specific environmental signals in plant cells, regulate plant physiological responses at low concentrations, and coordinate the growth, development, and differentiation of plants in different ways (Wen, 2015; Wang, 2018). The aging physiology of fresh cut flowers is inseparable from the action of endogenous hormones, such as the effects of auxin (IAA), gibberellin (GA), cytokinin (CTK), abscisic acid (ABA), and ethylene (ETH), whose changes in content and balance are closely related to the aging physiology of cut flowers (Sheng, 2022). McRae et al. (1982) believed that changes in endogenous hormone levels may be determining factors in the longevity of cut flowers. Ethylene is not the initiator of flower aging but can accelerate the process. During the aging process of cut flowers, the ethylene content of most plants gradually increases (Lu et al., 1998). Ethylene can change the permeability and composition of cell membranes, causing the leakage of cellular components, ultimately leading to water loss and wilting of petals, accelerating flower aging (Zhang & Guo, 2010). Zhang et al. (1991) found that the release of ethylene in long-lasting flowers is about 3-16 times that of short-lived flowers, suggesting that ethylene is an accelerator of aging rather than an initiator. Abscisic acid (ABA) is a natural hormone that promotes aging and shedding, and the concentration of ABA in the petals gradually increases with the opening and aging of cut flowers (Zheng, 1997). There is a complex interaction between ABA and ethylene. In carnations, the accumulation of ABA precedes the accumulation of ethylene (María et al., 2001). Treatment with exogenous ABA can induce ethylene production in carnations, as evidenced by the increased release of ethylene after treatment (Tomoko et al., 2000). Cytokinin (CTK) can reduce the respiration rate, promote water absorption, prevent protein degradation, and inhibit the yellowing of leaves of fresh cut flowers and potted plants, thus delaying aging (Ding, 1990). Exogenous cytokinin (6-BA) can reduce respiratory rate and promote water balance, thereby extending the vase life of cut flowers (Hu et al., 2014). CTK may also have an antagonistic effect with ABA (Xing et al., 2017). Gibberellin promotes increased plant cell numbers and elongation, further demonstrating its important role in plant growth and development. Gibberellin can also break plant dormancy, promote stamen differentiation, induce flowering, and delay leaf aging (Zhang, 2023; Liang, 2024). Both cytokinin and gibberellin (GA_3) show a declining trend during the aging process of cut flowers (Zheng, 1997). The effects of auxin (IAA) on different varieties of cut flowers vary. IAA can delay the vase life of iris but accelerate aging in lilies, orchids, and other flowers (Halevy & Mayak, 1981). The changes in IAA content during the aging process of different rose varieties show an increasing or decreasing trend, indicating that the trend varies with plant species (Halevy & Mayak, 1981). Additionally, the balance between endogenous hormones is closely related to the aging process. Zhang et al. (1991) found that the higher the CTK/ABA ratio, the slower the aging of cut flowers; the lower the ratio, the faster the aging. Yang et al.(1997) also found that the aging process of peony cut flowers corresponds to the change in the CTK/ABA ratio.

3. Types of preservative solutions for fresh-cut flowers

At present, the preservation techniques of fresh-cut flowers in China include chemical preservation techniques, physical preservation techniques, and gene regulation techniques. Among them, chemical preservation technology is the most commonly used preservation method, which utilizes different components of chemical preservative solutions to treat cut flowers and delay their senescence. This technique plays an important role in extending the vase life of fresh-cut flowers (Cao & Chen, 2015). According to the different uses of the preservative solutions, they can be divided into pretreatment solutions, flower-inducing solutions, and vase solutions (Xu, 1994). Pretreatment solutions, flower-inducing solutions, or vase solutions with different compositions have significant effects on the post-harvest transportation and sales process, flowering, and lifespan of cut flowers (Wang et al., 2023; Xiang et al., 2019).

3.1 Pretreatment solutions

Pretreatment solutions are used for preprocessing after the cutting of flowers, before storage, transportation, or vase arrangement. Their main purpose is to promote water absorption by flower stems, provide nutrients, sterilize, and reduce the harm caused by ethylene to the cut flowers during storage and transportation, thus delaying flower senescence and ensuring the opening quality of subsequent cut flowers.

3.2 Flower-inducing solutions

Flower-inducing solutions are used to promote the normal opening of cut flowers harvested during the bud stage before retail. The main purpose is to ripen the flower buds by providing nutrition and inhibiting the growth of microorganisms, promoting rapid flower bud opening, and thus reducing production costs. Bud harvesting refers to a method of harvesting cut flowers before the normal harvesting period, which can shorten the growth period of cut flowers, facilitate storage and transportation, and avoid waste of economic crops.

3.3 Vase solutions

Vase solutions are preservative solutions used during the viewing period after consumers purchase cut flowers. They mainly extend the vase life of cut flowers by replenishing consumed nutrients, improving water absorption by flower stems, and inhibiting microbial proliferation.

4. Main Components and Functions of Chemical Preservative Solutions

The various variable factors in cut flower preservative solutions, such as water, saccharides, organic acids, bactericides, plant growth regulators, and soluble inorganic salts, all affect the water absorption of cut flowers. Therefore, the solution intake and water balance of cut flowers can influence their vase life. The disruption of water balance within cut flowers is a crucial factor leading to the termination of their vase life. Adding certain chemical preservatives to the preservative solution can effectively alleviate the aging symptoms of cut flowers and extend their vase life, which has been verified in cut flowers such as lilies, roses, carnations, gerberas, orchids, clematis, calla lilies, and lisianthus (Cao et al., 2011; Wang et al., 2019; Dong et al., 2020; Wang et al., 2013). Wang et al. (2013) used a preservative solution containing sucrose, 8-HQ, and citric acid to treat the cut flowers of hydrangeas, which could slow down the change in fresh weight of flower stems, maintain water balance, and extend the vase life of hydrangeas. Meanwhile, using a preservative solution containing GA_3, GO, CA, and STS to treat peony cut flowers can effectively increase the relative water content of petals, the content of soluble proteins, and the activity of superoxide dismutase, alleviate the accumulation of free proline and malondialdehyde, and extend the blooming time of cut flowers (Si, 2022).

4.1 Water

Water quality has a significant impact on the vase life of cut flowers. Currently, there are three main types of water used in preservative solutions: (1) Tap water. Due to regional differences, tap water contains varying components, and tap water with excessively high alkalinity requires softening treatment to reduce its adverse effects on cut flowers. (2) Deionized water or distilled water. Because of its high purity, it can effectively enhance the durability of cut flower vases and enhance the effectiveness of preservative solutions. (3) Microporous membrane-filtered water. Its application is particularly widespread in cut flowers such as roses. The microporous membrane primarily removes bubbles through filtration and decompression, significantly reducing air blockage in the vascular bundle. Generally, tap water has adverse effects on cut flowers, while the use of distilled water, deionized water, or microporous membrane-filtered water can increase the vase life of cut flowers. Different types of cut flowers have varying requirements and sensitivities to water quality, with carnations, roses, and chrysanthemums being more sensitive, while tulips are relatively insensitive (Wang, 2021). The main factors affecting water quality are: (1) Acidity. A low pH value (3-4) is beneficial for cut flowers, effectively inhibiting the growth of microorganisms, preventing the blockage of vascular bundles in flower stems, and enhancing the water absorption capacity of stems, thus promoting water absorption by flower branches. (2) Total soluble substances. The degree of senescence of cut flowers is closely related to this indicator, and there are significant differences in the total demand for soluble substances among different cut flowers. When the total amount of soluble substances reaches 200 mg/L, the vase life of carnations, roses, and chrysanthemums is shortened, while gladioli only show adverse reactions when the total amount of soluble substances exceeds 700 mg/L (Xing, 2004).

4.2 Saccharides

Saccharide substances are one of the important components that were early applied in the field of cut flower preservation. As the main nutrient source and energy supply for cut flowers, saccharides largely determine the quality of cut flowers in vases (Xiong et al., 2021). Studies have shown that 10% sucrose treatment can extend the preservation period of gerbera cut flowers (Di et al., 2011). Using a vase solution containing sucrose, silver nitrate, and 8-HQS to preserve dahlia cut flowers can slow down the degradation of soluble saccharides and proteins, improve the activities of SOD, CAT, and POD, reduce MDA accumulation, and extend the vase life of flower branches (Xiong et al., 2021).

4.3 Organic acids

The pH value of the cut flower preservative solution has a significant impact on the vase life of cut flowers. For most plant cut flowers (such as dendrobium, gladioli, gerberas, etc.), a lower pH environment in the vase solution can effectively inhibit the reproduction of microorganisms, reduce the occurrence of stem vessel blockage, and promote water absorption by flower branches, which has a positive effect on the preservation of cut flowers (Regan & Dole, 2010; Saleem et al., 2014; Tonboot et al., 2015). In the study of gladioli cut flower preservation, it was found that citric acid significantly improved the water absorption capacity of flower branches by lowering the pH value of the vase solution, slowed down the senescence and wilting process caused by water loss in petal cells, and significantly extended the vase life of cut flowers (Wang et al., 2021). However, for specific types of cut flowers, such as carnations, roses, and hydrangeas, acidic solutions are not the best(He, 2021; Jiang et al., 2014; Li, 2022).

4.4 Bactericide

The stems of fresh-cut flowers often experience obstruction due to the proliferation of microorganisms in the vase solution, the invasion of bacteria into the xylem ducts, and the degradation of extracellular poly saccharide substances. This obstruction hinders the water absorption of cut flowers, thus shortening their vase life. Adding bactericide to the preservative solution can effectively inhibit the proliferation of microorganisms and reduce the damage to the water balance of flower branches, significantly extending the life of cut flowers (Huang, 2009). 8-Hydroxyquinoline (8-HQ) and its salts, such as 8-hydroxyquinoline citrate (8-HQC) and 8-hydroxyquinoline sulfate (8-HQS), are widely used as bactericides. These compounds have the property of binding to metals, which can deprive microorganisms of internal iron and copper ions, exhibiting powerful fungicidal and bactericidal effects. They can also reduce the physiological blockage of the vascular bundle tissue of flower stems and promote the water absorption ability of flower branches. Additionally, these compounds have the function of adjusting the pH value of water (i.e., changing the acidity and alkalinity of water). By reducing the pH value of water (i.e., increasing the acidity), they promote water absorption by flower branches and reduce stomatal opening, thereby reducing transpiration loss (Xia et al., 1997). Studies by Davood et al. (2021) have shown that treating carnations with 4.9×10^{-4}, 9.8×10^{-4}, and 2×10^{-3} mol/L of 8-HQS significantly extended the vase life of cut flowers, with the concentration of 2×10^{-3} mol/L showing the most significant effect.

4.5 Plant Growth Regulators

The senescence process of cut flowers, like other life activities, is controlled by hormone balance. Plant growth regulators achieve the purpose of extending the vase life of cut flowers by precisely regulating the balance between hormones. In recent years, with the advancement of science and technology, plant growth substances have been widely used in the research and development of chemical preservative solutions for fresh-cut flowers. Ethylene (Lu, 2022) and abscisic acid (ABA) (Cui et al., 2015) promote petal senescence, while cytokinins (CTK) (Wan et al., 2020; Zheng et al., 2009; Cheng et al., 2010; Wu et al., 2023; Zhang & Guo, 2005;

Yang et al., 2006) and gibberellins (GA) (Chen & Li, 2015; Yang et al., 2021) have significant effects on delaying the senescence of cut flowers. Additionally, auxins exhibit both delaying and promoting effects during the senescence process of cut flowers (Ye, 2005). Cytokinin-type growth regulators, such as kinetin, 6-benzyladenine (6-BA), and isopentenyl adenosine (IPA), are widely used in the practice of cut flower preservation. These substances can significantly extend the vase life of various cut flowers such as peony, carnation, gladiolus, chrysanthemum, and so on (Wan et al., 2020; Zheng et al., 2009; Cheng et al., 2010; Wu et al., 2023; Zhang & Guo, 2005; Yang et al., 2006). However, from the perspective of industrial development, these substances are usually costly, limiting their widespread application in large-scale production, and most research is still in the laboratory stage.

4.6 Soluble Inorganic Salts

The inorganic salts in the preservative solution can change the osmotic potential of the solution, regulate the internal and external pressure of petal cells, and enable the flower branches to absorb sufficient water to extend their vase life. Commonly used inorganic salts in cut flower preservative solutions include potassium, calcium, aluminum, silver, nickel, cobalt, and zinc (Chen et al., 2007). Studies have found that $CaCl_2$ in cut flower preservative solutions is beneficial for increasing the fresh weight of cut flowers, promoting flowering, increasing SOD, POD, and CAT activities, delaying the decline in protein content and relative conductivity, and extending the vase life of cut flowers (Liu, 2015).

5. Suggestions for the Development of Chemical Preservative Solutions

In the cut flower industry, the quality of cut flowers directly determines their ornamental and economic value, making the development of effective cut flower preservative solutions particularly important. With the continuous progress of science and technology, substances that can regulate the senescence of cut flowers are constantly being discovered in the research of preservative solutions, such as Nano Silver, plant essential oils, and other safer substances. Although significant progress has been made in the research of cut flower preservative solutions, further exploration is needed to achieve their widespread application in the cut flower industry. Currently, the high cost of chemical preservative solutions and potential environmental pollution issues cannot be ignored. Therefore, the development of efficient, low-cost, non-toxic, and harmless chemical preservative solutions for fresh-cut flowers is the focus of future work.

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