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Research Article

Synergistic Effects of Sucrose and Citric Acid on Vase Life in Cut Gerbera Flowers

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ABSTRACT

The ornamental value of Gerbera is severely limited by postharvest senescence, characterized by rapid wilting, stem bending, and pigment degradation. Conventional preservative solutions typically rely solely on sugars or organic acids, yielding inconsistent improvements in vase longevity. In this study, freshly harvested Gerbera `Jent' flowers were treated with 3.5% sucrose combined with citric acid (0–200 ppm) to evaluate their synergistic effects on vase performance under ambient conditions. Morphological parameters (vase life, fresh weight, water uptake, stem bending), physicochemical properties (pH, electrical conductivity), and biochemical traits (carotenoid, anthocyanin, soluble sugar, and malondialdehyde contents, respiration, and electrolyte leakage) were assessed. The combination of sucrose and citric acid, particularly at 150 ppm, markedly extended vase life from 8 to 15 days and improved water relations by maintaining higher fresh weight and sustaining water uptake above 35 mL per day, while also reducing stem curvature. Enhanced metabolic stability was evidenced by a 40% increase in pigment and sugar accumulation, along with a significant suppression of respiration. Membrane integrity was better preserved, as indicated by a reduction in electrolyte leakage to approximately 28% and a decrease in malondialdehyde levels by nearly one-third compared with the control. The synergistic interaction between sucrose and citric acid effectively delayed senescence by sustaining cellular homeostasis and oxidative balance. These findings identify an optimized preservative formulation for extending postharvest longevity in Gerbera, with practical implications for commercial floriculture and supply chain management.

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INTRODUCTION

Cut flowers, particularly *Gerbera jamesonii*, are widely valued in the floriculture industry for their vivid colors, unique architecture, and extended ornamental appeal[1]. However, their commercial value is often constrained by a relatively short vase life, primarily due to rapid loss of water balance, stem blockage, and postharvest physiological deterioration. Maintaining postharvest freshness remains a critical challenge because cut flowers are deprived of their natural nutrient supply and become highly susceptible to microbial proliferation and xylem occlusion, ultimately leading to premature wilting and floral collapse[2,3].

To mitigate postharvest deterioration, previous studies have investigated a wide range of vase solutions containing carbohydrates, organic acids, and antimicrobial agents, silver thiosulfate, 8-hydroxyquinoline sulfate, cytokinins, and ethylene inhibitors[4]. Among these, sucrose was found to play a central physiological role in extending vase life by serving as an exogenous energy source that sustains respiratory metabolism and delays carbon depletion in detached floral tissues. Exogenous sucrose supplementation helps maintain osmotic potential, thereby enhancing water retention and turgor pressure in petals[5]. In addition, sucrose supports continued cell expansion, preserves membrane stability, and delays senescence-related processes by downregulating hydrolytic enzyme activity and reducing the degradation of structural carbohydrates and proteins[6]. At the molecular level, sucrose also modulates senescence-associated gene expression and suppresses ethylene biosynthesis and sensitivity in certain cut flower species, contributing to delayed petal wilting and discoloration[7]. However, the beneficial effects of sucrose are highly dependent on its interaction with the vase solution environment. In the absence of antimicrobial or acidifying agents, sucrose-rich solutions may promote microbial proliferation, resulting in xylem occlusion and impaired hydraulic conductivity. This paradox underscores the importance of combining carbohydrate supplementation with agents that can maintain solution hygiene and facilitate water transport. Citric acid extends vase life primarily through its effects on solution pH and microbial control. By lowering the pH of the vase solution, citric acid inhibits bacterial growth and reduces the formation of microbial biofilms at the cut stem surface[8]. Acidic conditions also improve xylem wettability and reduce the formation of air emboli sms, thereby enhancing water uptake efficiency.

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Beyond its antimicrobial role, citric acid can stabilize cellular membranes and mitigate oxidative stress by maintaining ionic balance and reducing lipid peroxidation, indirectly delaying senescence in floral tissues[9].

Previous studies have shown that the combined application of sucrose and citric acid can be more effective than either compound alone in extending vase life in several cut flower species, including rose, carnation, and Gerbera[10,11]. These studies indicate that sucrose primarily supports metabolic activity and energy supply, whereas citric acid enhances water uptake by regulating solution pH and reducing microbial-induced stem blockage[12]. However, physiological responses to this combined treatment are species-specific and may vary considerably even among cultivars within the same species. In Gerbera, limited information is available on cultivar-specific responses, particularly for cultivars such as 'Jent,' which are highly sensitive to water stress and stem occlusion. Consequently, the influence of sucrose and citric acid on water balance, membrane stability, and senescence processes in 'Jent' remains insufficiently characterized. In the present study, we aim to evaluate the synergistic effects of sucrose and citric acid on the vase life of cut Gerbera flowers, with particular emphasis on water balance and cell integrity. By clarifying their combined physiological effects, this research seeks to advance our understanding of preservative formulation and support improved postharvest handling practices in the floriculture industry.

MATERIALS AND METHODS

Plant material and experimental design

Cut Gerbera 'Jent' flowers were harvested from healthy, uniform plants grown in the same cultivation area at the Business Incubation Center, High-Tech Agriculture Park (Cu Chi District, Ho Chi Minh City), ensuring consistent plant age and growth conditions. Flowers were collected at commercial maturity, i.e., when one to two outer ray florets were fully open. Freshly harvested flowers were transported on the same day to the Plant Physiology Laboratory at the University of Sciences, Vietnam National University, Ho Chi Minh City. Upon arrival, stems were gently cleaned to remove surface contaminants and recut under deionized water to a uniform length of 30 cm to prevent air embolism.

The experiment followed a completely randomized design with five treatments, each comprising five replicates and ten flowers per replicate. Each stem was placed individually in a glass test tube (20 cm in height $\times$ 2 cm in diameter) containing 40 mL of a solution composed of 3.5% sucrose supplemented with citric acid (CA) at concentrations of 0, 50, 100, 150, or 200 ppm. All samples were maintained under ambient laboratory conditions (30 ± 2 °C and 65 ± 5% relative humidity). Morphological parameters were recorded periodically throughout the vase-life period. Physiological and biochemical analyses were conducted using five independent replicates.

Physiological and biochemical assessment

Vase life and stem bending

tem bending was evaluated daily using a 180° protractor. Each stem was aligned with the baseline of the protractor, where 0° indicated a fully upright position and 90° denoted a right-angle bend. Vase life was determined as the number of days from the onset of treatment until irreversible senescence. A cut flower was considered senescent when $\geq$50% of the petals showed wilting, peduncle bending, and discoloration sufficient to render the flower commercially unacceptable. Stems were observed daily under controlled conditions (22 ± 2 °C, 60–65% relative humidity, and a 12-h photoperiod), and the termination day was recorded for each stem.

Water uptake rate

Daily water uptake was quantified by measuring the decrease in solution volume in each vase over a 24-h period. To account for evaporation, blank vases without flowers served as controls. Water uptake was expressed in mL/day and calculated as follows: Water uptake = (Initial volume − Final volume) − Evaporation loss.

Electrolyte leakage, electrical conductivity, and pH

Cell membrane permeability was determined according to the standard conductivity method[13]. Fresh petal segments were rinsed with deionized water and immersed in 10 mL of deionized water in test tubes, followed by incubation at room temperature (25 ± 1 °C) for 4 h. The initial electrical conductivity (C_1) of the bathing solution was recorded using a conductivity meter. Samples were then autoclaved at 100 °C for 15 min, cooled to room temperature, and the final conductivity (C_2) was measured. Electrolyte leakage was expressed as EL (%) = (C_1/C_2) $\times$ 100. The physicochemical properties of the petal extract and vase solution were monitored daily. pH and electrical conductivity (EC) were measured using calibrated digital meters to assess ionic variation over time.

Malondialdehyde content

Lipid peroxidation, an indicator of oxidative membrane injury, was quantified by measuring malondialdehyde (MDA) content using the thiobarbituric acid

(TBA) assay[14]. Approximately 0.5 g of fresh petal was homogenized in 0.1% (w/v) trichloroacetic acid (TCA) and centrifuged at 10,000 × g for 10 min. The supernatant (1 mL) was mixed with 4 mL of 0.5% (w/v) TBA in 20% (w/v) TCA, and the reaction mixture was heated at 95 °C for 30 min. After rapid cooling in an ice bath, absorbance was measured at 532 nm.

Carotenoid content

Fresh petal samples (1 g) were extracted using 5 mL of 96% ethanol and centrifuged at 5,000 rpm for 3 min. The residue was re-extracted twice under the same conditions. The supernatants were pooled and adjusted to a final volume of 50 mL with 96% ethanol. Absorbance was measured at 470, 648, and 664 nm using a UV–Vis spectrophotometer. Total carotenoid content was calculated according to Lichtenthaler's formula[15].

Anthocyanin content

Anthocyanin content was determined using the pH differential method. Fresh petal samples (1 g) were finely homogenized in 10 mL of an acetone:methanol:water mixture (35:35:30, v/v/v) and centrifuged at 10,000 rpm for 5 min. The supernatant was collected, and a 0.5-mL aliquot was mixed separately with 4.5 mL of 0.2 N KCl buffer (pH 1.0) or 0.2 N sodium acetate buffer (pH 4.5). After incubation for 15 min at room temperature, absorbance was measured at 520 and 700 nm using a spectrophotometer[16].

Respiratory rate and sugar content

A closed chamber equipped with a CO_2 analyzer (EA80, Extech, USA) was used to measure gas exchange[17]. Respiration was recorded in darkness under controlled conditions (30 ± 1 °C and 75 ± 2% relative humidity). oluble sugar were extracted from petal homogenates using ethanol. The extracts were reacted with phenol and concentrated H_2SO_4, and absorbance was measured at 490 nm[18].

Statistical analysis

All data were analyzed using one-way analysis of variance (ANOVA) with SPSS software. When significant differences were observed at the 5% significance level ($p < 0.05$), treatment means were compared using Duncan's multiple range test.

RESULTS

Effects of sucrose and citric acid on morphological characteristics of cut Gerbera flowers

Figure 1 illustrates the combined effects of sucrose and citric acid on key postharvest parameters, including vase life, fresh weight, water uptake rate, and stem bending. The results showed a pronounced synergistic interaction when citric acid was incorporated into the sucrose solution, leading to markedly improved outcomes compared with sucrose alone or the control. Control flowers exhibited the shortest vase life, averaging approximately 8 days, whereas sucrose alone moderately extended vase life to approximately 10 days. By contrast, the combined application of sucrose with citric acid, particularly at 150 ppm, substantially increased vase life to up to 15 days. This synergistic effect was further supported by fresh weight retention. Although sucrose alone improved water balance to some extent, the sucrose–citric acid combinations consistently maintained higher fresh weights throughout the evaluation period. Similarly, the combined treatments notably enhanced the water uptake rate. Flowers treated with sucrose and 100–150 ppm citric acid achieved the highest uptake levels (>35 mL day^{-1}), clearly surpassing both the control and sucrose-only treatments. Conversely, stem bending followed an opposite trend. While severe bending occurred in the control group (>50°), the combined sucrose and citric acid treatments significantly reduced stem curvature to below 35° across the 100–200 ppm range.

Visual differences in floral morphology among treatments were evident throughout the vase period (Figure 2). Control flowers exhibited pronounced wilting, characterized by shriveled ray florets and visible deformation of the floral head. The petals appeared desiccated, curled inward, and displayed discoloration, transitioning to a dull, faded yellow. Disc florets at the center also showed early collapse and browning, indicating rapid senescence. By contrast, flowers treated with sucrose alone maintained better structural integrity, although slight curvature and marginal wilting of ray florets were still observed. The disc florets remained relatively compact however, some loss of turgidity was apparent. A marked improvement was observed in flowers treated with the combined sucrose and citric acid solutions. At 100–200 ppm CA, the inflorescences retained a vibrant golden-yellow color, with fully expanded and uniformly arranged ray florets. The capitulum remained symmetrical, and disc florets were firm, indicating delayed senescence. Petal margins remained intact, with no signs of shriveling or browning.

Sucrose- and citric acid-induced changes in cut flower physiology and biochemistry

After 10 days of treatment, clear differences were observed in both petal and vase solution electrical conductivity (Figure 3). The control exhibited the lowest

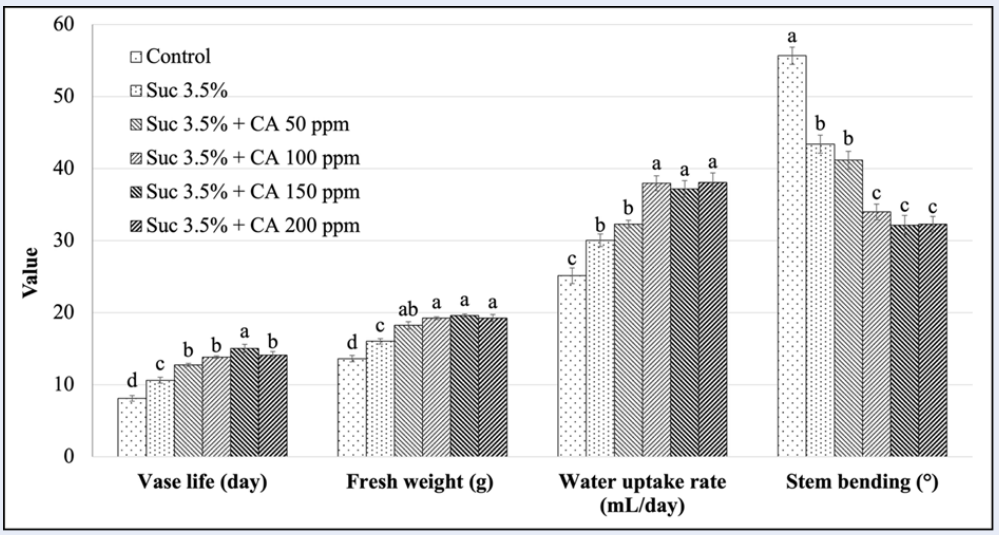

Figure 1: Effects of sucrose and citric acid on vase life,fresh weight, water uptake, and stem bending of cut Gerbera after 10 days. Means within the same measured parameter with different letters differ significantlyat $p < 0.05$. [Source: Authors']

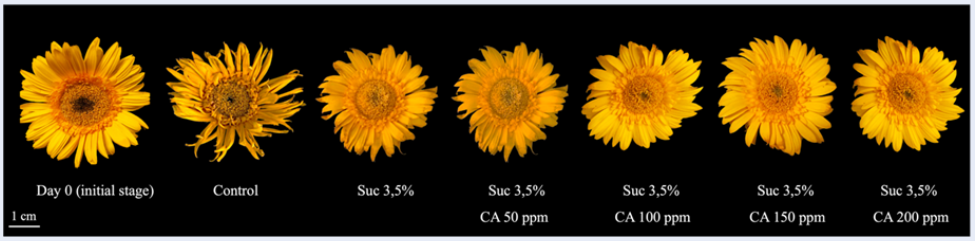

Figure 2: Morphological responses of cut Gerbera flowers to sucrose and citricacid after 10 days [Source: Authors']

petal conductivity (approximately 0.5 mS/cm). ucrose treatment increased this value to approximately 0.9 mS/cm, whereas the combination of sucrose and citric acid resulted in higher conductivity values, ranging from approximately 1.5 to 1.8 mS/cm. By contrast, the vase solution showed an opposite trend. The highest conductivity occurred in the control and sucrose treatments, reaching nearly 2.3 mS/cm, while the addition of citric acid led to reduced conductivity to approximately 1.5–1.8 mS/cm. Treatments supplemented with citric acid showed pH values of approximately 6.1, whereas lower pH values (approximately 5.1) were observed in the control and sucrose treatments. A clearer differentiation among treatments was evident in the vase solution. The control and sucrose treatments exhibited relatively high pH levels, ranging from approximately 7.8–8.0, while the addition of citric acid markedly reduced the solution pH to approximately 4.2–5.8.

Figure 4 presents the effects of preservative treatments on carotenoid and anthocyanin contents, as well as soluble sugar levels and respiratory rate, in cut flowers. Compared with the control, which displayed the lowest pigment and sugar levels, the combined application of sucrose and citric acid markedly enhanced all biochemical attributes. Carotenoid content increased by approximately 42% under treatments containing 100–200 ppm citric acid, while anthocyanin content increased by approximately 48%. The most substantial improvement occurred in soluble sugar content, particularly under the treatment combining sucrose with 150 ppm citric acid. Under this treatment, values nearly doubled relative to the control and exceeded those of the sucrose-only treatment by approximately 33%, highlighting the synergistic interaction between sucrose and citric acid. Conversely, respiratory activity declined across the combined treatments. The lowest respiration rate was recorded in

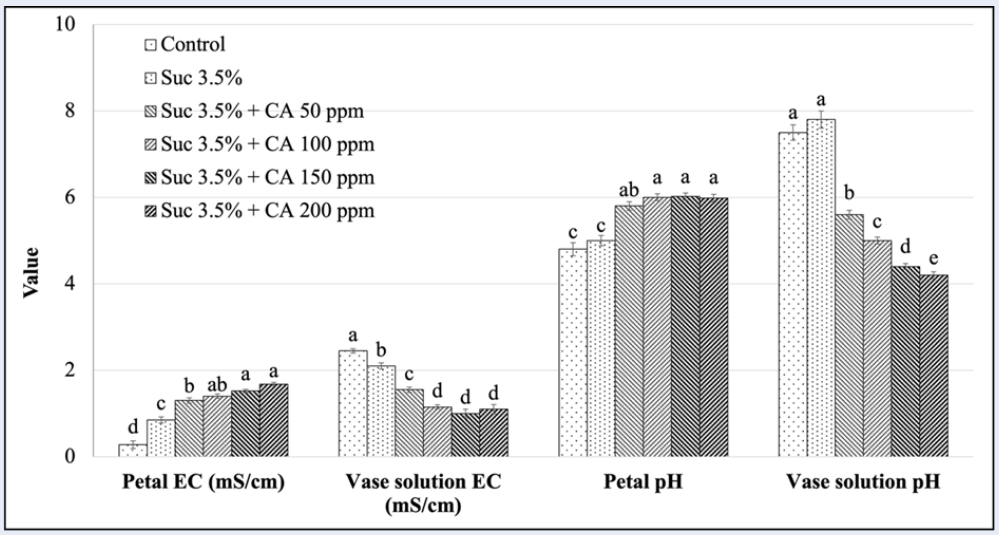

Figure 3: EC and pH of petal extracts and vase solutions of cut flowers after 10 days of treatment. Different lowercase letters above the bars indicate significant differences among treatments($p < 0.05$). [Source: Authors']

flowers treated with sucrose and 150 ppm citric acid, reaching nearly 40% below that of the control.

Marked differences in membrane stability were observed among treatments, as indicated by variations in electrolyte leakage and MDA content (Figure 5). Control flowers exhibited the highest electrolyte leakage, reflecting severe cellular disruption. By contrast, the combination of sucrose and citric acid, particularly at concentrations of 150–200 ppm, reduced leakage to approximately 28%, indicating substantially improved membrane integrity. A similar pattern was observed for lipid peroxidation. MDA levels were highest in the control, whereas treatments combining sucrose with citric acid consistently maintained lower values. Formulations containing 100–200 ppm citric acid showed the greatest reduction, with MDA content decreasing by nearly 33% compared with the control, demonstrating enhanced protection against oxidative damage under these synergistic treatments.

DISCUSSION

The combined application of sucrose and citric acid appeared to delay senescence in cut Gerbera flowers by improving water relations, carbohydrate status, and membrane integrity in a coordinated manner. Although the extension of vase life was the most apparent outcome, the associated physiological indicators suggest a broader modulation of postharvest metabolism. Flowers maintained in control solutions showed early stem bending and floret wilting, whereas those treated with 100–150 ppm sucrose–citric acid solutions retained structural integrity significantly longer (Figure 1), indicating a more stable internal water balance. This improvement in hydration is likely associated with the acidification of the vase solution by citric acid, which may have limited xylem blockage[19]. Treated stems exhibited higher solution uptake and reduced bending (Figure 1), while capitula retained symmetry and petal firmness (Figure 2), suggesting restored cellular turgor. Although microbiological parameters were not assessed, these visual outcomes are consistent with previous reports that acidic solutions reduce vascular occlusion[20,21].

In addition to hydration, enhanced carbohydrate retention appeared to support floral maintenance. The higher soluble sugar content observed in treated petals (Figure 4) indicates improved energy availability, which may sustain basic metabolic activity. Concurrently, the reduced respiration rate (Figure 4) suggests a metabolic shift toward conservation, thereby preventing rapid depletion of reserves. The stabilization of internal petal pH (Figure 3) further indicates that sucrose uptake occurred under favorable proton gradients, potentially facilitating H^+–sucrose cotransport[22]. Citric acid may also have influenced intracellular metabolism beyond its role in external pH adjustment. As an intermediate of the tricarboxylic acid cycle, its presence could have moderated mitochondrial flux, contributing indirectly to reduced respiratory intensity[23,24]. Membrane stability emerged as a key factor distinguishing treated from untreated

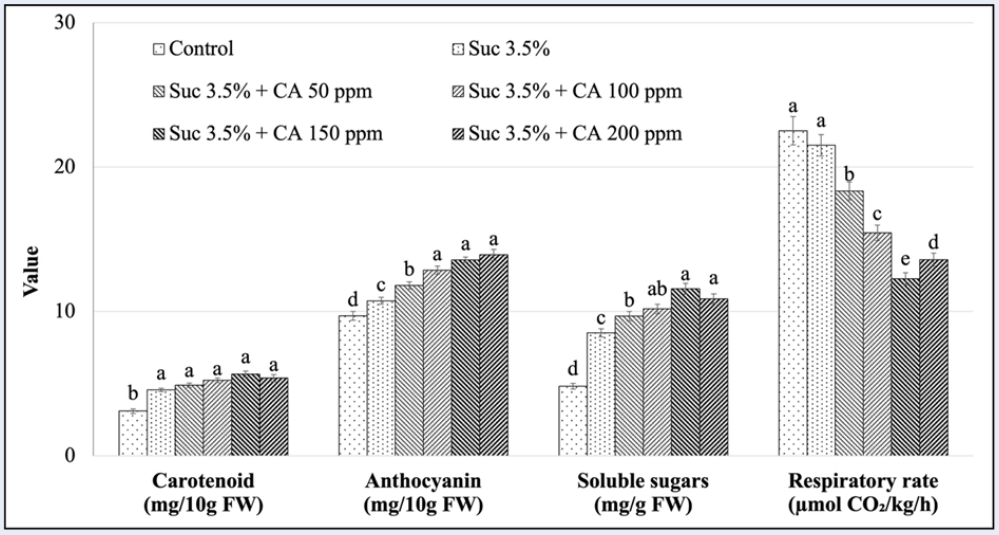

Figure 4: Carotenoid and anthocyanin contents, soluble sugar levels, and respiratory rate of cut flowers after 10 days of treatment. Different lowercase letters above the bars indicate significant differences among treatments ($p < 0.05$). [Source: Authors']

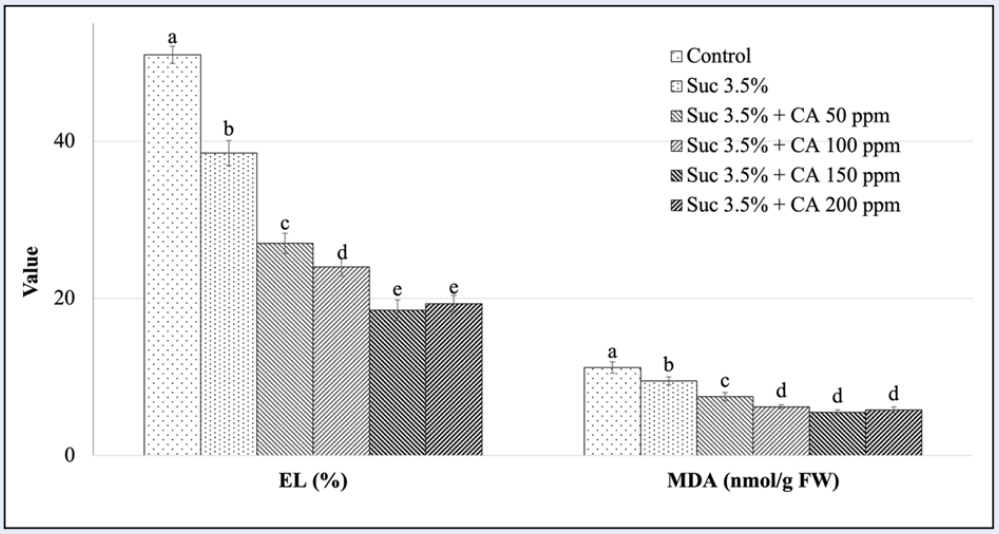

Figure 5: Electrolyte leakage (EL) and malondialdehyde (MDA) content in the petals of cut flowers after 10 days oftreatment. Different lowercase letters above the bars indicate significant differences among treatments ($p < 0.05$). [Source: Authors']

flowers. Lower electrolyte leakage and reduced MDA accumulation (Figure 5) indicate decreased lipid peroxidation and improved cellular integrity [25]. The preserved petal architecture observed in treated flowers (Figure 2) is consistent with reduced oxidative damage. Although antioxidant activity was not quantified, the balance between carbohydrate supply and moderated respiration likely contributed to limiting ROS formation [26]. Overall, our results suggest that sucrose and citric acid function through complementary pathways rather than as simple preservatives. Their combined effect were most evident at moderate concentrations, indicating that precise formulation is important to avoid osmotic or metabolic imbalance. Although the present findings are limited to visual and biochemical indicators, they offer practical relevance for improving the postharvest quality of Gerbera and potentially other cut flowers susceptible to hydraulic and oxidative stress.

CONCLUSIONS

The combined application of sucrose and citric acid proved highly effective in prolonging vase life and maintaining the postharvest quality of cut Gerbera flowers. Integrated treatments, particularly at 150–200 ppm citric acid, improved water balance, preserved floral integrity, and delayed visible senescence. These effects were supported by increased pigment and soluble sugar accumulation, reduced respiration rates, and improved membrane stability, as evidenced by lower electrolyte leakage and MDA content. The findings of this study highlight sucrose–citric acid formulations as a practical and efficient preservative strategy for improving the commercial longevity and quality of cut flowers within supply chains.

ABBREVIATIONS

CA: Citric acid
EC: Electrical conductivity
EL: Electrolyte leakage
FW: Fresh weight
MDA: Malondialdehyde
ROS: Reactive oxygen species
SPSS: Statistical package for the social sciences
TBA: Thiobarbituric acid
TCA: Trichloroacetic acid

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHOR'S CONTRIBUTIONS

Conceptualization: Thang Thanh Tran and Tien Thi Thuy Le; Methodology: Ha Thi Xuan Vu and Linh Minh Hong Tran; Formal analysis and investigation: Ha Thi Xuan Vu, Phuc Hoang Nguyen, and Tien Thi Thuy Le; Writing - review and editing: Thang Thanh Tran. All authors read and approved the final manuscript.

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