BMC Plant Biology

RESEARCH Open Access

Lysophosphatidylethanolamine (LPE) improved the vase life of cut gerbera flowers

Onur Sefa Alkaç[1*] and Onur Saraçoğlu[1]

Abstract

The post-harvest quality and vase life of cut gerbera (*Gerbera jamesonii* Bolus ex. Hooker) flowers are critical quality parameters that affect their marketability and consumer satisfaction. This study was conducted to determine the effects of vase solutions containing different ratios of lysophosphatidyl ethanolamine (LPE), streptomycin, citric acid, and sucrose on vase life, water uptake, fresh weight change, phenolic compounds, and oxidative stress responses. In addition to morphological parameters, biochemical markers such as superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), and malondialdehyde (MDA) were examined to evaluate the antioxidant defense mechanisms in the flowers. Among the treatments, the T9 group (1 ppm LPE + 200 mg L^{-1} streptomycin + 200 mg L^{-1} citric acid + 5% sucrose) and the T10 group (2 ppm LPE + 200 mg L^{-1} streptomycin + 200 mg L^{-1} citric acid + 5% sucrose) stood out as the most effective treatments, exhibiting the highest vase life, water uptake, and lowest MDA content. In contrast, the highest POD and MDA levels were detected in the T6 treatment (2 ppm LPE). Although no statistically significant difference was observed in CAT activity, the high average values in the 200 mg L^{-1} citric acid treatment (T4) suggest that it may play a role in H_2O_2 detoxification. Additionally, increases in secondary metabolite levels such as phenolic compounds, flavonoids, anthocyanins, and total antioxidant activity were observed throughout the vase life, indicating that the plant synthesizes these compounds as a defense against oxidative stress during the aging process. The findings suggest that LPE, when used in combination with antibacterial and metabolic support agents, offers an effective strategy for extending the vase life of cut flowers by reducing oxidative damage.

Keywords *Gerbera jamesonii*, Anti-bactericide, Vase life, Ethylene, Cut flower, Phenolic compounds, Oxidative stress

Introduction

Gerbera jamesonii is an important cut flower species belonging to the Asteraceae family [1]. It is a very popular cut flower species with double, semi-double, and single flowers [2]. The flower structure consists of a composite containing three types of rays, trans, and disk flowers. Due to its color variety, flower size, long life, and wide adaptability, it is in high demand worldwide for greenhouse cultivation [3]. Gerbera flower varieties are generally classified into standard and small sizes. In standard varieties, flower diameters range from 10 to 13 cm, while some varieties can reach up to 15 cm in flower diameter [4]. Globally, Gerbera ranks fifth in the cut flower market [5].

The vase life of cut flowers is a very important characteristic that determines their quality and the satisfaction level of consumers who purchase them [6, 7]. It is also known that cut gerberas show low sensitivity to ethylene [8]. Stem bending (scape bending), flower abscission, petal wilting, and other defects are also believed to reduce

*Correspondence:
Onur Sefa Alkaç
onur.alkac@gop.edu.tr
[1]Department of Horticulture, Faculty of Agriculture, Tokat Gaziosmanpaşa University, Tokat, Türkiye

the ornamental value of cut gerberas [9]. In particular, stem bending is an important factor that shortens vase life [10–12]. The post-harvest longevity of cut flowers depends on various physiological and biochemical factors [13]. Inhibiting bacterial growth in vase water can reduce the incidence of stem bending, suggesting that bacteria are the primary cause of this defect [14]. One of the physiological effects is temperature, which is one of the most important factors affecting cut flowers. Post-harvest low-temperature treatment slows down metabolic processes such as respiration and transpiration, thereby reducing the activity of carbohydrate and other substance reserves, water, ethylene production, and microorganisms [15–20]. Consequently, the lifespan of flowers is extended, which enhances the marketing potential of the products. This is particularly important for short-lived cut flower species [21, 22]. Another important factor affecting post-harvest quality is the composition of the vase solution in which the flowers are placed. Sugars and antibacterial agents are two essential components of vase solutions. Sugars are an important part of flower nutrition and provide cut stems with the necessary carbohydrates to sustain metabolic processes and extend vase life. Sugars should be used in combination with antimicrobial compounds to prevent microbial buildup in solutions [23]. A new antibacterial compound, 'streptomycin,' has begun to take its place among the compounds used to prevent microbial growth. Streptomycin is the first aminoglycoside antibiotic discovered, originally isolated from the '*Streptomyces griseus*' bacterium [24]. Streptomycin belongs to a group of compounds known and produced as antibiotics. It inhibits the growth and development of microorganisms and may even result in their complete elimination [25, 26]. It has also been reported that streptomycin has additional activity against double aerobic gram-negative bacteria [24]. Another important factor is the intensity of ethylene synthesis, and as the intensity of ethylene synthesis increases, signs of aging in plants rapidly increase, leading to the rapid death of cut flowers. To prevent or minimize this, the use of low-temperature treatment and/or a new substance containing the active ingredient Lysophosphatidylethanolamine (LPE), which inhibits ethylene synthesis, is being considered. LPE is a natural product of membrane phospholipid metabolism. It is known to have significant effects on the quality of flowers, fruits, and other garden products [27]. Studies have provided evidence that LPE accelerates the ripening of tomatoes and cranberries while also extending their shelf life [28, 29]. It has also been found that LPE treatment reduces the aging of leaves, fruits, and cut flowers [30–33]. Additionally, due to its natural properties, lack of residue issues, and effective improvement of quality characteristics in many fruits, vegetables, and ornamental plants, the importance of LPE is increasing day by day [34]. Studies on the use of LPE in cut flowers are limited. However, some research has demonstrated the positive effects of LPE in different species. For example, it has been reported that LPE treatments in carnations delay leaf senescence by preserving membrane integrity [35], increase the vase life of 'Lavande' and 'Sensation' roses [36], and suppress ethylene-induced senescence in snapdragon flowers [37]. These findings support the original contribution of our study regarding LPE treatments in cut flowers.

Studies aimed at extending the vase life of cut flowers have increased in recent years. However, literature reviews reveal that research on the use of LPE and Streptomycin alone or in combination in ornamental plants is limited. Therefore, this study was conducted to determine the effects of different vase solutions on the post-harvest vase life and quality criteria of *Gerbera jamesonii* flowers.

Materials and methods

Plant material

Gerbera (*Gerbera jamesonii* L.) flowers used in this study were obtained from a commercial greenhouse producing Gerbera. Harvesting was done early in the morning and care was taken to ensure that the plants were healthy, homogeneous and had two rows of male organs [38].

Experimental design and treatments

Harvested flowers were transported to the laboratory in buckets filled with water. For preliminary water absorption treatments, all plants were kept in water for 6 h under room conditions. The experimental design of the experiment (at the end of the 6th hour in the environment, plants were kept under room conditions, and quality parameters were then analyzed) is as follows (Fig. 1):

Gerbera cut flowers were all cut into 40 cm length and placed into eleven different vase solutions containing LPE (Flora Q+, Nutra-Park, Republic of Korea) streptomycin (Sigma-Aldrich), citric acid (Merck, Millipore Corporation) and sugar-supplemented (Merck, Millipore Corporation) combinations (Table 1). The content of all vase solutions was determined as 500 mL.

Vase life (day)

Vase life is defined as the number of days from the day the flowers were placed into the vase (onset) to the day when the flowers were wilting and/or the flower stalk is bent more than 90° [39].

Relative fresh weight (RFW)

Relative fresh weight (RFW) was measured on day 0 (onset) and on days 2, 4, 6 and 8 following the initiation of experiments. Calculations were made with the use of the following equation [40]:

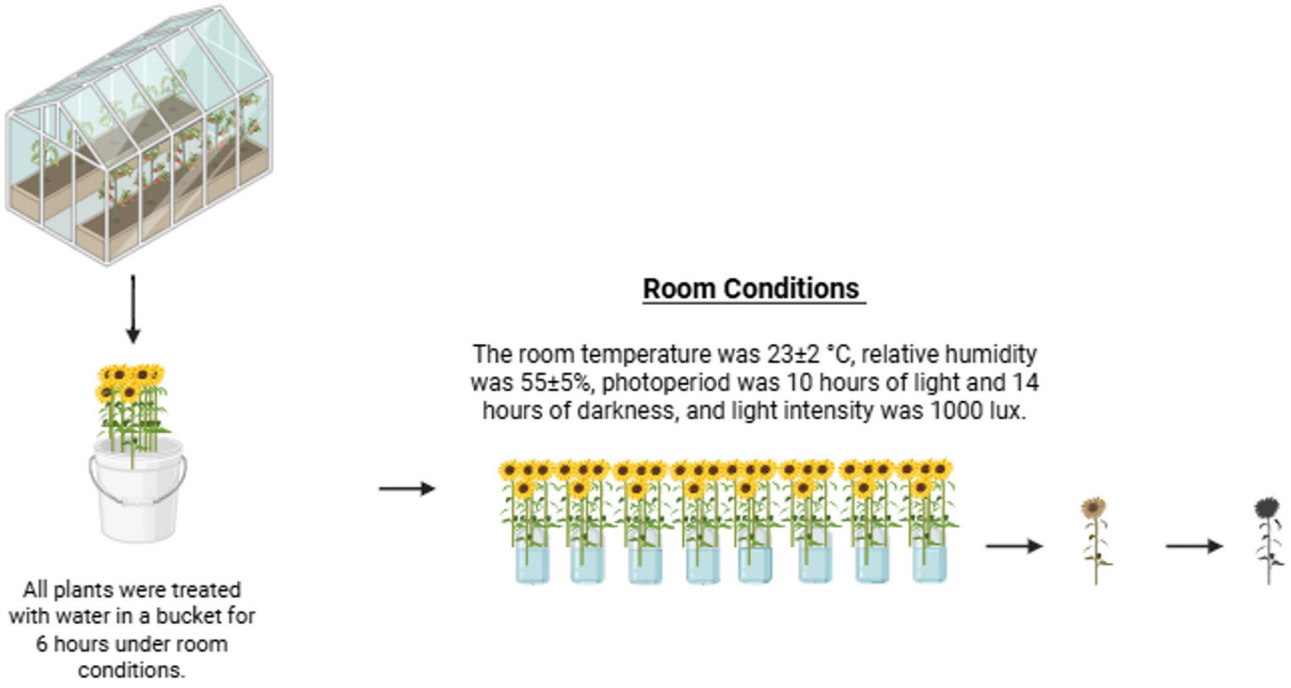

Fig. 1 An image of the work plan

Table 1 Vase solutions and concentrations

Treatment	Concentration
T1: Distilled water (Control) (mL)	-
T2: Sugar (%)	5
T3: Streptomycin (mg L^{-1})	200
T4: Citric Acid (mg L^{-1})	200
T5: LPE (ppm)	1
T6: LPE (ppm)	2
T7: LPE (ppm)	4
T8: Streptomycin (mg L^{-1}) + Citric Acid (mg L^{-1}) + Sugar (%)	200 + 200 + 5
T9: LPE (mL L^{-1}) + Streptomycin (mL L^{-1}) + Citric Acid (mL L^{-1}) + Sugar (%)	1 + 200 + 200 + 5
T10: LPE (mL L^{-1}) + Streptomycin (mL L^{-1}) + Citric Acid (mL L^{-1}) + Sugar (%)	2 + 200 + 200 + 5
T11: LPE (mL L^{-1}) + Streptomycin (mL L^{-1}) + Citric Acid (mL L^{-1}) + Sugar (%)	4 + 200 + 200 + 5

$$\mathrm{RFW}\ (\%) = (\mathrm{Wt}/\mathrm{Wt0}) \times 100$$

Wt: Stalk weight at day t (2, 4, 6, etc.)
Wt0 = Stalk weight at day 0.

Daily vase solution uptake (DVSU)

Daily vase solution uptake was calculated with the use of the following equation [41]:

$$\mathrm{DVSU} = (\mathrm{WSt} - 1) - (\mathrm{WSt})$$

WSt-1 = Previous day weight of vase solution.
WSt = Weight of vase solution on day t (2, 4, 6, etc.).

Total vase solution uptake (TVSU)

Total vase solution uptake was calculated with the use of the following equation [41]:

$$\mathrm{TVSU} = \mathrm{A} - \mathrm{B}$$

A: Weight of vase solution at onset
B: Weight of vase solution at the end of vase life.

Determination of bioactive compounds in flower petals

Fifteen petals were selected from each flower for bioactive compounds, and these petals were collected on the sixth day. These petals were then homogenized with a homogenator. The homogenates were placed in 3 different tubes and stored at −20 °C for bioactive analyses. The samples were melted at room temperature (≈21 °C) and homogenized in a mixer. The obtained samples were centrifuged at 4 °C for 30 min (12,000 g). Freshly obtained petal samples were divided into multiple aliquots to dilute with distilled water. Phenolics were refrozen at −20 °C until used in anthocyanin and antioxidant assay procedures.

Total phenolics

Total phenolic content was measured according to the procedure described by Singleton and Rossi [42]. Briefly, the extract of petals was extracted with a buffer containing acetone, water and acetic acid (70:29.5:0.5 v/v) for 2 h in the dark. Samples were repeated four times. The extracts were mixed with Folin-Ciocalteu phenol reagent

and water and incubated in the chamber for 8 min, followed by the addition of 7% sodium carbonate. After 2 h, the absorbance at 750 nm was measured on an automatic UV-vis spectrophotometer (Model T60U, PG Instruments). Results are expressed as micrograms (µg) of gallic acid equivalent (GAE) g^{-1} fresh weight (fw).

Total flavonoids

Total flavonoid content was measured according to the procedure described by Zhishen et al. [43]. Absorbances were determined at a wavelength of 510 nm. The results were expressed as milligrams (mg) catechin equivalent (CE) L^{-1} fresh weight (fw).

Antioxidant capacity test

The samples were dissolved in 10 mmol L^{-1} ABTS (2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid) acetate buffer and mixed with potassium per sulphate [44]. The mixture was diluted to an absorbance of 0.700 ± 0.01 at 734 nm using acidic medium of 20 mM sodium acetate buffer (pH 4.5) for longer stability. For spectrophotometric analysis, 2.90 mL ABTS + solution and 100 µL petal extract were mixed and incubated for 10 min at room temperature in the dark. Absorbance was then determined at 734 nm. The results were expressed as µmol trolox equivalent (TE) g^{-1} fw.

Total monomeric anthocyanin

Total anthocyanin levels were measured using the pH difference method described by Giusti and Wrolstad [45]. Sample extracts were combined in separate dishes with potassium chloride and sodium acetate buffers (pH 1.0 and 4.5, respectively) in a 1:20 ratio (h: v). After an equilibration time (15 min), the raw absorbance of each solution was measured at 533 and 700 nm. The corrected absorbance value was calculated as [(A520-A700) pH 1.0-(A520-A700) pH 4.5]. Anthocyanin content was calculated using the molar absorptivity (ϵ) and molecular weights (MW) of cyanidin 3-glycoside (ϵ = 26.900; MW = 449.2). Results are expressed as micrograms (µg) of cyanidin 3-glucoside equivalents (µg cy-3-glu g^{-1} fw).

Determination of antioxidant enzyme analyses in flower petals

During the vase life of gerbera petals, antioxidant enzyme analyses were determined; peroxidase (POD), superoxide dismutase (SOD), malondialdehyde (MDA) content to detect lipid peroxidation, and catalase (CAT) were measured.

Peroxidase (POD)

Peroxidase enzyme activity was measured using a method modified from Change and Maehly [46] and Pourzarnegar et al. [47]. Peroxidase enzyme activity was determined based on the oxidation of guaiacol to tetraguaiacol in the presence of hydrogen peroxide. The reaction solution was prepared to contain 50 mM potassium phosphate buffer (pH 6.5), 20 mM guaiacol, and 20 mM H_2O_2. For analysis, 0.2 mL of enzyme extract was added to 2.5 mL of the reaction solution to initiate the reaction. The absorbance change was monitored at 470 nm wavelength for 1 min using a spectrophotometer. Activity was expressed as U g^{-1} fresh weight based on the increase in absorbance over 1 min.

Superoxide dismutase (SOD)

Changes in SOD activity were determined by the inhibition of nitroblue tetrazolium (NBT) at a wavelength of 560 nm. The reaction solution consisted of a mixture of 50 mM Na-phosphate buffer ($Na_2HPO_4{\cdot}2H_2O$), 0.1 mM Na-EDTA, 33 µM NBT, 5 µM riboflavin, and 13 mM methionine (pH = 7.0). 2.5 ml of reaction solution was mixed with 0.1 ml of cherry extract. The reaction was carried out at 25 °C under light at 75 µmol m^{-2} s^{-1} (40 W) for 10 min. The control solution was incubated in the dark without enzyme for the same duration. The control and reaction solutions were read at 560 nm. SOD activity was determined as the activity that reduced 50% of NBT [48, 49].

Malondialdehyde (MDA)

Malondialdehyde (MDA) content was determined to detect lipid peroxidation in samples taken from the petals of Gerbera flowers throughout their vase life. A 0.5 g sample taken from the petals of Gerbera flowers was homogenized with 10 ml of 0.1% trichloroacetic acid (TCA), and the homogenate was centrifuged at 12,000 rpm for 10 min. One milliliter of the supernatant was taken and mixed with 4 ml of 20% TCA solution containing 0.5% thiobarbituric acid (TBA). The mixture was incubated at 95 °C for 30 min, then rapidly cooled in an ice bath. The malondialdehyde (MDA) content was calculated using the following equation after determining the absorbance at 532 and 600 nm wavelengths [49].

MDA (nmol ml^{-1}) = $[(A_{532}\text{-}A_{600})/155.000]10^6$.

Catalase (CAT)

The catalase activity of Gerbera petals throughout their vase life was determined by monitoring the disappearance of H_2O_2 at a wavelength of 240 nm. A reaction solution consisting of 0.05 M phosphate buffer (KH_2PO_4) and 1.5 mM H_2O_2 was used (pH = 7.0). 2.5 mL of reaction solution was mixed with 0.2 mL of cherry extract. Readings were taken at 240 nm wavelength at 0 and 60 s using a spectrophotometer. The reaction was initiated by adding 0.2 mL of enzyme extract. The evaluation was performed by considering the change in absorbance within 1 min [48, 49].

Statistical analysis

The experiments were conducted in a randomized experimental design with three replications, and three cut flowers were used in each replication [50]. Vase life was measured daily and other parameters were measured every two days. The results obtained were evaluated by analysis of variance (ANOVA) in SPSS (IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp.) statistical program. Duncan multiple comparison test was applied to determine the significance of the differences between treatments.

Results

Relative fresh weight changes in gerbera plants in the room conditions were found to be significant. As of the 8th day, the highest relative fresh weight value was recorded in T9 (1 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar) (103.57%), which did not fall below the initial weight value proportionally. The highest loss (17.57%) compared to the initial weight ratio was found in T1 (Control) treatment (82.43%). In the first environment, the effects of 11 different treatments on daily vase solution uptake in gerbera plants were found to be significant. As of day 6–8, the highest daily vase solution uptake was measured in T9 treatment (1 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar) (9.74 mL). From the 2nd day onwards, daily vase solution uptake started to decrease. As of day 6–8, the lowest daily vase solution intake was measured in T7 (4 ppm LPE) treatment (4.97 mL). In general, the daily vase solution uptake was the highest on days 2–4, while the daily solution uptake decreased steadily in the following measurements. In the first stage, the effect of treatments on vase life was found to be statistically significant. The highest vase life was found in T9 treatment (1 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar) (10.81 days) and the lowest vase life was found in T7 treatment (4 ppm LPE) (6.67 days). The data obtained in total vase solution uptake in the first stage were found to be significant. The highest vase solution uptake was recorded in T9 treatment (1 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar) (67.72 mL) and the lowest vase solution uptake was recorded in T7 (4 ppm LPE) treatment (38.31 mL). These results also reflected the effects on vase life. With the increase in daily vase solution intake, the highest total vase solution intake was recorded in T9 treatment (1 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar). The highest vase life was also recorded in the T9 treatment and is also reflected in the visuals (Figs. 2, 3 and 4). There were significant differences in vase life among the 11 different treatments ($p < 0.001$). The longest vase life (13.77 days) was obtained from treatment T7 (4 ppm LPE), while the shortest vase life (8.22 days) was obtained from treatment T1 (Control).

pH changes

Significant changes were observed between the initial and final pH values of the vase solutions belonging to different treatments. The initial pH values ranged from 3.40 to 7.30, with the lowest pH measured at 3.40 in the T4 (200 mg L^{-1} Citric acid) and T6 (2 ppm LPE) treatments. The highest initial pH value was detected in the T5 (1 ppm LPE), T8 (200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar), and T10 (2 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar) groups, ranging from 7.20 to 7.30. In general, a decrease in pH was observed in all treatments; the most pronounced decrease occurred in the T2 (5% Sugar) group, where the pH value dropped from 5.40 to 2.40. This situation is thought to be due to the sugar content promoting microbial growth, causing the solution to become acidic. In treatments containing combinations such as T9 (1 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar), T10 (2 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar), and T11 (4 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar), despite the high initial pH, the values after the first change remained in the range of 6.42–6.87. The limited pH decrease in these groups suggests that the solution provides a more stable environment from a microbial perspective. Overall, the treatments with the most stable pH values were T5 (1 ppm LPE) and T10 (2 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar), while the greatest pH decrease was recorded in the T2 group (Fig. 5).

The effects of different treatments on total phenol (µg GAE g^{-1} fw), total flavonoids (mg KE L^{-1} fw), total monomeric anthocyanin (µg cy-3-glu g^{-1} fw) and total antioxidant activity (µmol TE g^{-1} fw) in gerbera petals were statistically significant. On the 6th day, the highest total phenol (4241.12), the highest total flavonoid (1306.67), the highest total monomeric anthocyanin (621.20) and the highest total antioxidant activity (84.96) were determined in T4 treatment (200 mg L^{-1} Citric acid). The lowest total phenol (1771.12), total flavonoid (525.19), total monomeric anthocyanin (242.69) amounts were recorded in T3 treatment (200 mg L^{-1} Streptomycin), while total antioxidant activity (66.21) was measured in T2 treatment (5% Sugar) (Fig. 6).

In this study, the effects of different treatments on the antioxidant enzyme activities of peroxidase (POD), superoxide dismutase (SOD), catalase (CAT), and malondialdehyde (MDA) levels, which are oxidative stress indicators, in *Gerbera jamesonii* petals were investigated. POD (Peroxidase) activity showed significant differences depending on the treatment ($p < 0.001$). The lowest POD

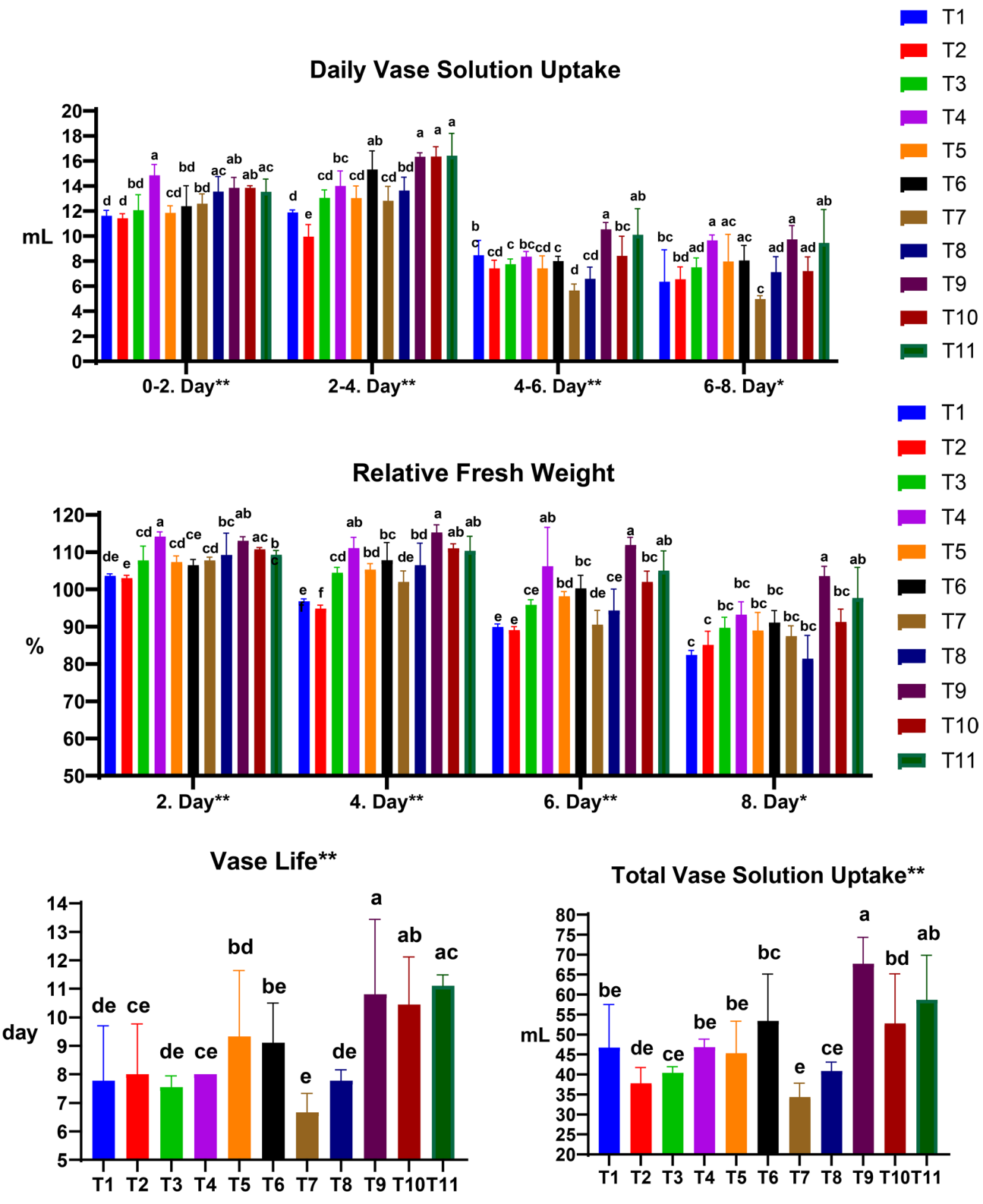

Fig. 2 Effects of different treatments on daily vase solution uptake (mL), relative fresh weight change (%), vase life (days), and total vase solution uptake in cut *Gerbera jamesonii* flowers. T1: Control (Distilled water); T2: Sugar (5%); T3: Streptomycin (200 mg L^{-1}); T4: Citric acid (200 mg L^{-1}); T5: LPE (1 ppm); T6: LPE (2 ppm); T7: LPE (4 ppm); T8: Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T9: LPE (1 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T10: LPE (2 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T11: LPE (4 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%). The columns represent means, and the bars represent standard errors of the three replicates, * $p < 0.05$, ** $p < 0.001$

Fig. 3 Effects of different treatments on the vase life of cut *Gerbera jamesonii* flowers (6th day). T1: Control (Distilled water); T2: Sugar (5%); T3: Streptomycin (200 mg L^{-1}); T4: Citric acid (200 mg L^{-1}); T5: LPE (1 ppm); T6: LPE (2 ppm); T7: LPE (4 ppm); T8: Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T9: LPE (1 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T10: LPE (2 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T11: LPE (4 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%)

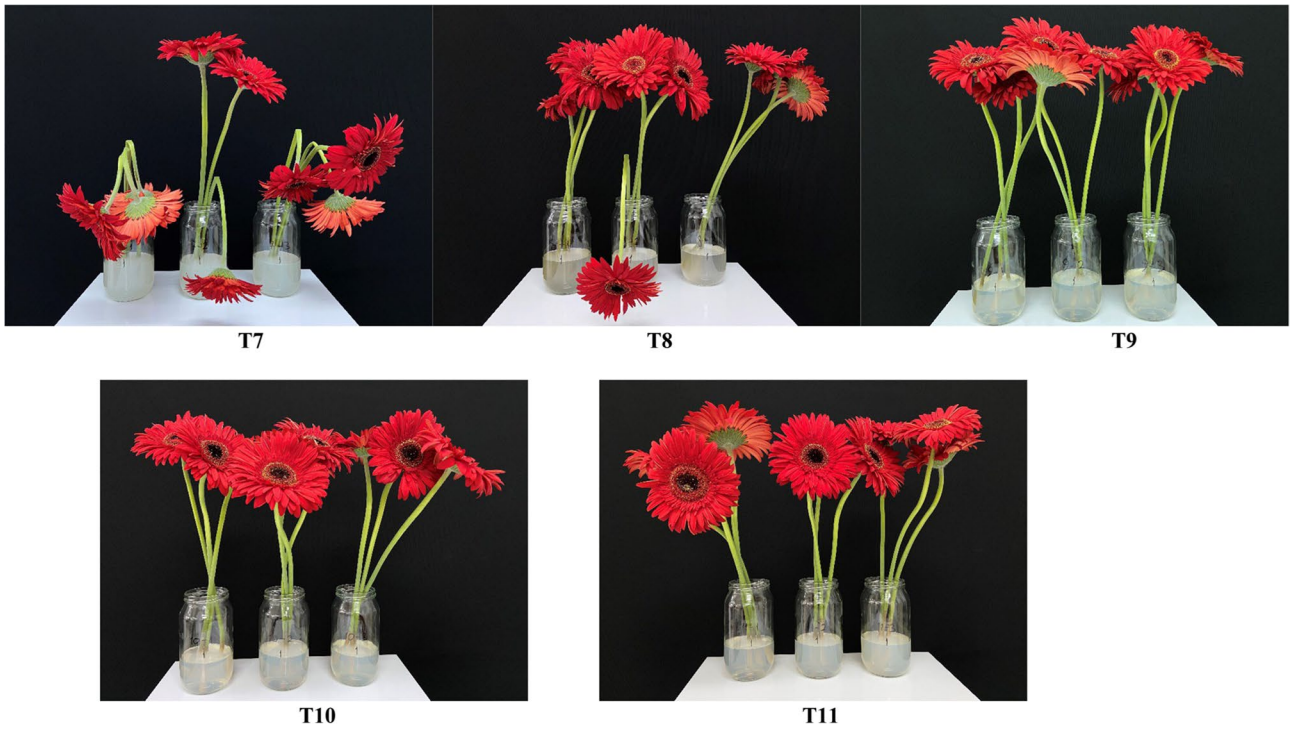

Fig. 4 Effects of different treatments on the vase life of cut *Gerbera jamesonii* flowers (6th day) (continued from previous page). T1: Control (Distilled water); T2: Sugar (5%); T3: Streptomycin (200 mg L^{-1}); T4: Citric acid (200 mg L^{-1}); T5: LPE (1 ppm); T6: LPE (2 ppm); T7: LPE (4 ppm); T8: Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T9: LPE (1 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T10: LPE (2 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T11: LPE (4 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%)

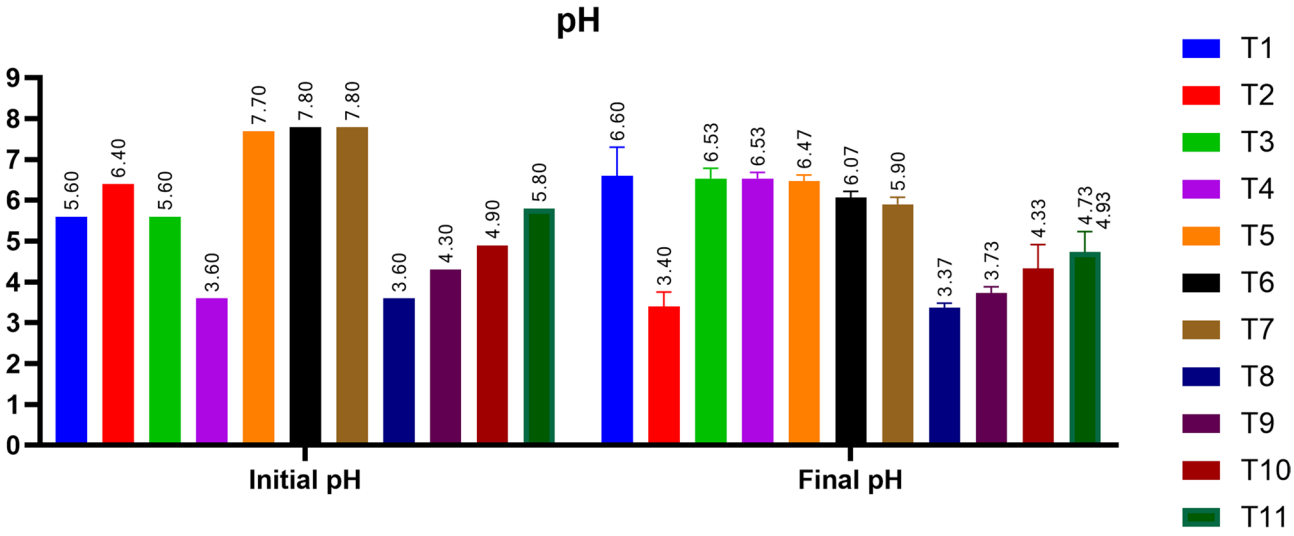

Fig. 5 Initial and final pH changes of different vase solutions used in the study. T1: Control (Distilled water); T2: Sugar (5%); T3: Streptomycin (200 mg L^{-1}); T4: Citric acid (200 mg L^{-1}); T5: LPE (1 ppm); T6: LPE (2 ppm); T7: LPE (4 ppm); T8: Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T9: LPE (1 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T10: LPE (2 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T11: LPE (4 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%). The columns represent means, and the bars represent standard errors of the three replicates

levels were observed in the T2 (5% Sugar; 8.70 U g^{-1} FW) and T11 (4 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar; 9.40 U g^{-1} FW) treatments, and these groups were statistically grouped together in the same subgroup. The highest POD values were measured in the T7 (4 ppm LPE; 40.40 U g^{-1} FW) and T6 (2 ppm LPE; 35.63 U g^{-1} FW) treatments, and these two treatments were statistically different from each other. These findings indicate that medium and high-dose LPE treatments significantly increase POD activity. Statistically significant differences were also found between the treatments in terms of SOD (superoxide dismutase) activity ($p < 0.001$). The lowest SOD activity was observed in the T6 treatment (2 ppm LPE; 57.17 U g^{-1} FW). In contrast, the highest SOD levels were measured in the T10 (2 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar; 222.17 U g^{-1} FW) and T11 (4 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar; 196. 20 U g^{-1} FW) treatments, with these two treatments statistically belonging to the highest group. This finding indicates that combined treatments containing high doses of LPE significantly activate the SOD enzyme, whereas LPE alone at moderate doses may inhibit this enzyme. MDA (malondialdehyde) levels, an important parameter reflecting the effects of treatments on oxidative stress, showed significant differences in this study ($p < 0.001$). The lowest MDA levels were observed in the T10 (2 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar; 3.03 mM g^{-1} FW) and T3 (200 mg L^{-1} Streptomycin; 4.07 mM g^{-1} FW) groups, which represented the statistically lowest oxidative damage group. In contrast, the highest MDA values were observed in the T7 (4 ppm LPE; 16.37 mM g^{-1} FW) and T6 (2 ppm LPE; 15.40 mM g^{-1} FW) treatments, suggesting that LPE may cause harmful effects when applied alone at high doses and may lead to oxidative damage in cell membranes by increasing lipid peroxidation.

When examined in terms of CAT (catalase) activity, only the T4 (200 mg L^{-1} Citric acid) treatment was found to show a significantly higher value. The high CAT activity measured in the T4 (200 mg L^{-1} Citric acid) group indicates that this treatment may be effective in the detoxification of reactive oxygen species such as hydrogen peroxide. No significant differences were observed among the other treatments, and these groups exhibited similar levels of low CAT activity (Fig. 7).

Discussion

This study contributes to the understanding of various physiological and biochemical factors affecting the vase life of cut *Gerbera jamesonii* flowers. Our research aimed to determine the effects of vase solutions containing different ratios of LPE, citric acid, sucrose, and streptomycin on water uptake, fresh weight loss, and vase life of flowers. However, the effects of the treatments were not limited to morphological parameters; oxidative stress levels and defense system responses in flower petal tissues were also evaluated through biochemical markers such as superoxide dismutase (SOD), peroxidase (POD), malondialdehyde (MDA) and catalase (CAT). The T9 (1 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar) treatment emerged as the most effective treatment, exhibiting the highest vase life and water uptake. This is reported to be due to streptomycin's high

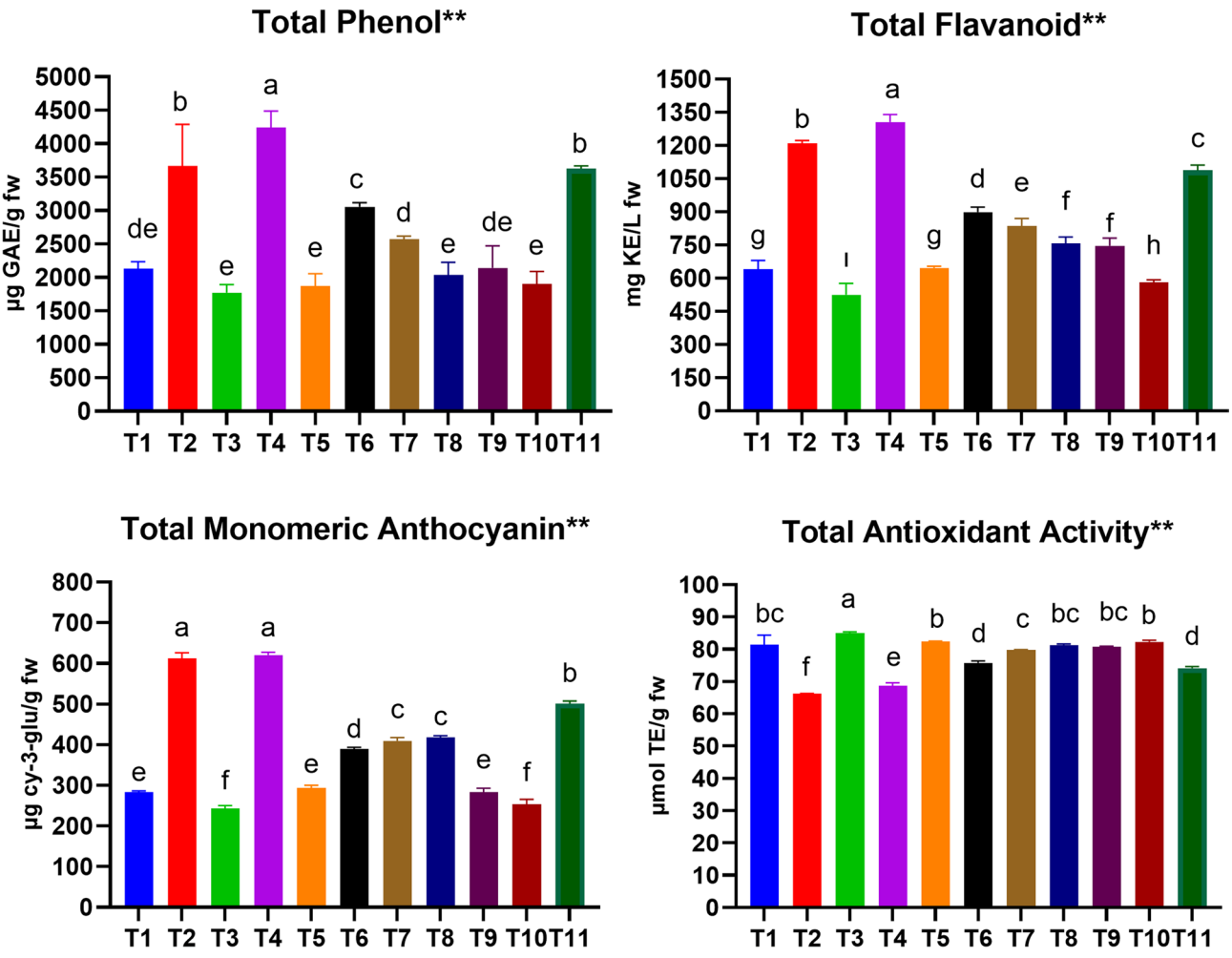

Fig. 6 Effects of different treatments on total phenol (µg GAE g^{-1} FW), total flavonoid (mg KE L^{-1} FW), total monomeric anthocyanin (µg Cy-3-glu g^{-1} FW), and total antioxidant activity (µmol TE g^{-1} FW) in *Gerbera jamesonii* petals on day 6. T1: Control (Distilled water); T2: Sugar (5%); T3: Streptomycin (200 mg L^{-1}); T4: Citric acid (200 mg L^{-1}); T5: LPE (1 ppm); T6: LPE (2 ppm); T7: LPE (4 ppm); T8: Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T9: LPE (1 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T10: LPE (2 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T11: LPE (4 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%). The columns represent means, and the bars represent standard errors of the three replicates, $^{*}p < 0.05$, **: $p < 0.001$

antibacterial activity, which is effective against both gram-positive and gram-negative bacteria [44]. The addition of streptomycin to vase solutions is thought to prevent bacterial blockage in the plant stem, with this effect increasing at higher doses. Al-Humaid [45] noted that the combination of 20% sugar and 250 ppm streptomycin treatments extended vase life in 'Rose Supreme' and 'Nova Lux' varieties. Nair and Chung [50] reported that sucrose and antibacterial agents added to vase solutions extended the vase life of cut flowers. Our findings in gerbera demonstrate that the combination of streptomycin with LPE provides an additional contribution beyond streptomycin alone, highlighting the potential of LPE as a synergistic postharvest treatment. Similar findings were obtained in this study, and it was observed that the combination of streptomycin, which has antibacterial properties, and sugar both prevented bacterial growth and nourished the plants. Additionally, other studies have indicated that biocides with antibacterial properties extend the vase life of gardenia flowers [51]. Li et al. [52] reported that silver nanoparticles with antibacterial properties reduce bacterial density and thus prevent bacterial formation on the stems of cut gladiolus 'Eerde' variety. Damunupola and Joyce [53] and Faragher et al. [54] emphasized that bactericides can have multiple effects and highlighted the importance of their mechanisms of action in plants. In the T7 treatment (4 ppm LPE), the vase life duration was the shortest, and it was identified as the lowest treatment in terms of daily and total vase solution uptake. On the 6th day, the highest total phenol (4241.12), the highest total flavonoid (1306.67), the highest total monomeric anthocyanin (621.20), and the highest total antioxidant activity (84.96) were determined in the T4 treatment (200 mg L^{-1} Citric acid). The

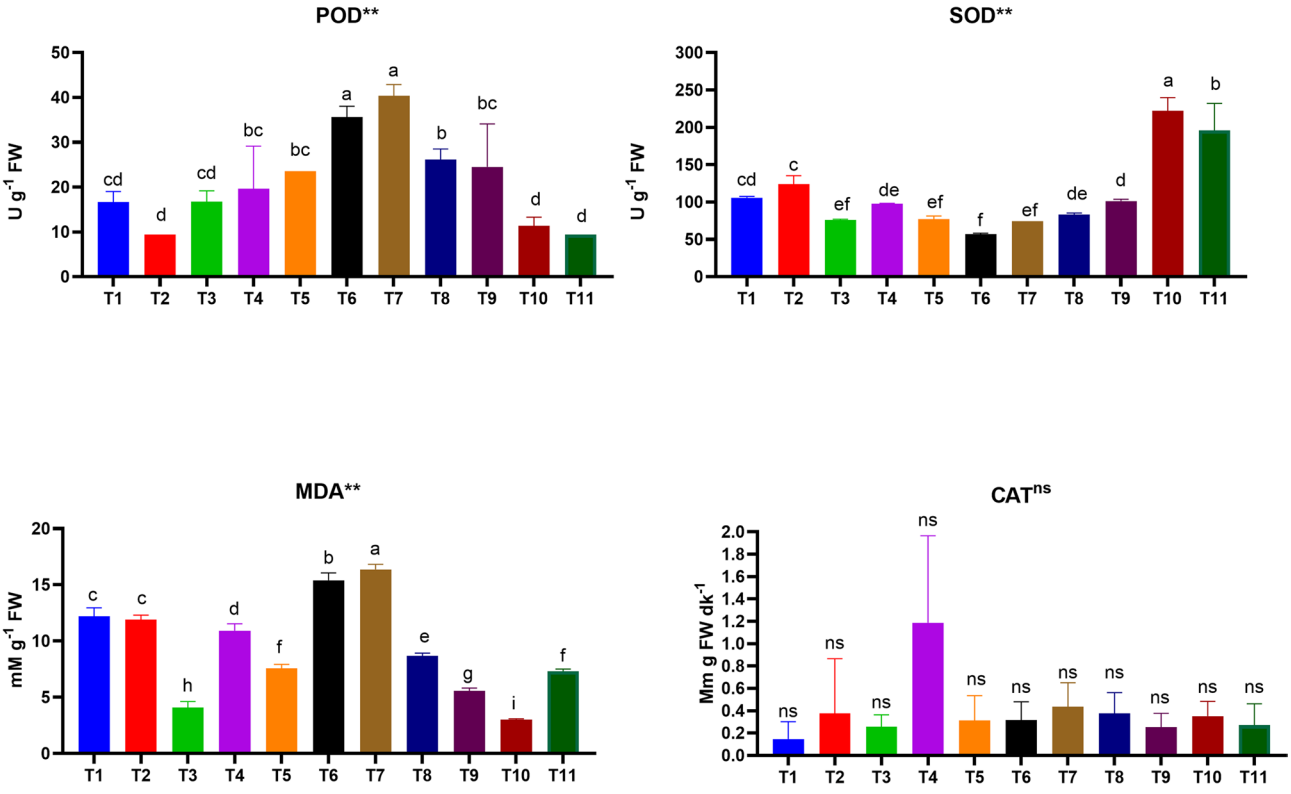

Fig. 7 Effects of different treatments on peroxidase (POD), superoxide dismutase (SOD), and malondialdehyde (MDA) contents in the leaves of *Gerbera jamesonii*. T1: Control (Distilled water); T2: Sugar (5%); T3: Streptomycin (200 mg L^{-1}); T4: Citric acid (200 mg L^{-1}); T5: LPE (1 ppm); T6: LPE (2 ppm); T7: LPE (4 ppm); T8: Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T9: LPE (1 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T10: LPE (2 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%); T11: LPE (4 ppm) + Streptomycin + Citric acid + Sugar (200 mg L^{-1} + 200 mg L^{-1} + 5%). The columns represent means, and the bars represent standard errors of the three replicates, $^{*}p < 0.05$, $^{**}p < 0.001$. ns: non-significant

lowest total phenol (1771.12), total flavonoid (525.19), and total monomeric anthocyanin (242.69) amounts were recorded in the T3 treatment (200 mg L^{-1} Streptomycin), while total antioxidant activity (66.21) was measured in the T2 treatment (5% Sugar). An increase in phenolic content was observed throughout the vase life of *Gerbera jamesonii* petals. This can be explained by the plant synthesizing phenolic compounds as a defense mechanism against oxidative stress [55]. To our knowledge, this is the first report demonstrating the effect of combining LPE with an antibacterial agent in gerbera. While streptomycin alone has previously been reported to improve vase life in species such as rose, snapdragons and carnation, no studies have investigated its combination with LPE. Our results therefore indicate a novel mechanism, suggesting that LPE may act synergistically with streptomycin to enhance postharvest longevity. The preservation of anthocyanins and the overall increase in TPC highlight the complex metabolic changes in the plant's aging process. This trend can be interpreted as a stress response mechanism in which phenolic compounds are synthesized as part of the plant's defense against oxidative stress associated with aging. The increase in total flavonoid content (TFC) observed in *Gerbera jamesonii* leaves can be linked to several interrelated mechanisms. The increase in flavonoid production as a defense against oxidative stress associated with aging in plants may have triggered the activation of key enzymes such as phenylalanine ammonia lyase (PAL) and chalcone synthase (CHS), leading to increased flavonoid synthesis [56]. In general, the high vase life and solution uptake have caused a decrease in biochemical content. This may be attributed to the decrease in vase life and subsequent stress on the plants due to reduced solution uptake. This, in turn, may have promoted an increase in biochemical content.

In this study, it was observed that streptomycin had a positive effect on the water uptake of Gerbera plants and yielded better results when combined with LPE (lysophosphatidyl ethanolamine) treatment. This effect is thought to stem from the synergistic effect of streptomycin's antibacterial properties and LPE's mechanism of inhibiting ethylene synthesis. Thus, bacterial growth was inhibited and xylem blockage was reduced. It is also thought that the longer vase life provided by the T9 (1 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric

acid + 5% Sugar), T10 (2 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar), and T11 (4 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar) treatments compared to other treatments is related to this effect. The data in Fig. 2 support these results. When examining the effects of the treatments on relative fresh weight, it was determined that relative fresh weight losses increased as the number of days increased. This decrease is associated with negative effects such as high ethylene synthesis, slowed water uptake, and consequently, the shedding, yellowing, wilting, and browning of flowers, leaves, and petals [57]. These processes have led to a shortened vase life of the flowers. Gerbera flowers are known to be highly sensitive to ethylene. The premature wilting of some cut flowers has been associated with bacterial blockage in the flower stems [57–59]. In particular, it has been reported that increased bacterial growth at the basal root tips blocks the flow of nutrients from the root tips to other parts of the flowers or leaves [57, 58]. Stockwell et al. [60] reported that antibiotics and antibacterials colonize better in the stem region, are more effective against pathogens in this region, and inhibit bacterial growth through antibacterial agents. Additionally, it has been noted that these substances are widely preferred because they prevent the blockage of xylem vessels and maintain water balance [61]. The inhibition of water transport along the stem causes water deficiency in plants, leading to wilting and reducing water uptake rates [62–64]. Throughout the study, it was determined that the total and daily vase solution uptake amounts were high. This situation was primarily explained by different treatments and temperature regimes. The fact that the study was conducted under room conditions led to high respiration rates, easy utilization of vase solutions by plants, and increased evaporation. When examining the effects of treatments on total vase solution uptake, it was observed that the combination of LPE + citric acid + antibacterial streptomycin + sugar treatments yielded the best results. It was determined that these combinations directly affected total vase solution uptake by preventing xylem blockage.

The effects of various compounds (sugar, streptomycin, citric acid, LPE, and their combinations) applied to cut gerbera flowers on oxidative stress markers were evaluated. The findings show that the treatments caused significant differences in antioxidant enzyme activities (SOD, POD, CAT) and MDA levels, which are indicators of oxidative damage. The highest POD (peroxidase) activity values were measured in the T6 (2 ppm LPE) and T7 (4 ppm LPE) groups, and these two groups were statistically significantly different from all other groups. This indicates that high-dose LPE treatment strongly activates the peroxidase enzyme system. LPE can disrupt oxidative balance by affecting phospholipid content in cell membranes, as well as triggering defense systems. However, the effect of high-dose LPE alone may also serve as an indicator of increased oxidative stress within the cell. In this context, the activation of the antioxidant system by LPE can be considered a reflection of the stress response resulting from excessive ROS production. The highest SOD (superoxide dismutase) activity was observed in the T10 (2 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar) group, which was statistically distinct from all other groups. The T10 treatment (2 ppm LPE + 200 mg L^{-1} streptomycin + 200 mg L^{-1} citric acid + 5% sugar) produced the strongest defense response against superoxide radicals. This result demonstrates that the combination treatment, particularly due to synergistic effects, provides a more balanced and effective antioxidant defense against oxidative stress in plants. These findings are consistent with the results observed by Wang et al. [65] in carnations treated with ClO_2, indicating that the combined management of microbial control and antioxidant defense is effective in delaying flower senescence. In contrast, the lowest SOD activity observed in the T6 group suggests that 2 ppm LPE applied alone may inhibit this enzyme or fail to provide sufficient stimulation. This finding indicates that the use of LPE at high doses alone may lead to imbalances in antioxidant defense systems. MDA (malondialdehyde) levels were evaluated as an indicator of lipid peroxidation in cell membranes, and the highest MDA value was detected in the T6 group (2 ppm LPE). This suggests that high-dose LPE, despite increasing POD activity, may fail to prevent cellular membrane damage and may instead exacerbate oxidative damage. On the other hand, the lowest MDA value was measured in the T10 group (2 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar), followed by the T3 (200 mg L^{-1} Streptomycin) and T9 (1 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar) treatments. The low MDA levels observed in these groups indicate that the treatments suppressed lipid peroxidation and protected cell membrane integrity. In particular, it is thought that the streptomycin treatment in the T3 group (200 mg L^{-1} Streptomycin) indirectly contributed to the alleviation of oxidative stress by reducing the microbial load. No statistically significant difference was detected between the groups in terms of CAT (catalase) activity. However, the visually highest average value observed in the T4 group (200 mg L^{-1} citric acid) suggests that this treatment may be effective in defending against specific ROS types such as hydrogen peroxide. In addition to citric acid's pH-regulating and chelating effects, previous studies have also indicated that it may support CAT activity through the detoxification of H_2O_2 in antioxidant systems. However, due to the high variability in this study, this effect did not reach statistical significance.

When evaluated overall, the T10 treatment (2 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar) stands out as an treatment that effectively suppresses oxidative stress with high SOD activity, low MDA levels, and controlled POD activity. This combination has ensured the coordinated functioning of enzymatic defense systems and minimized lipid peroxidation. The T6 treatment (2 ppm LPE), on the other hand, drew attention with high POD and MDA levels, indicating a stress response characterized by both high defense and high damage. Kaur and Palta [37] demonstrated in snapdragons that low concentrations of LPE improved flower longevity while higher doses became phytotoxic. Consistent with this, our results in gerbera provide the first evidence that LPE exerts similar dose-dependent effects in this species, thereby confirming that the contradictory influence of LPE depending on dosage may represent a broader mechanism in cut flowers. The T3 (200 mg L^{-1} Streptomycin) and T9 (1 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar) treatments were also found to be effective in maintaining cell membrane stability with low MDA levels. Although there was no significant difference in CAT levels, the high average value observed in the T4 group (200 mg L^{-1} Citric acid) suggests that this treatment may play a role in H_2O_2 detoxification. High concentrations of LPE may promote membrane phospholipid degradation, resulting in increased ROS accumulation and oxidative stress, thereby accelerating senescence. The elevated oxidative stress markers in gerbera under high-dose LPE confirm this mechanism, consistent with previous reports [37, 66]. Although the combination of streptomycin and LPE was effective, the potential risks of antibiotic resistance and environmental impacts cannot be overlooked [67, 68]. In this context, future research should also focus on sustainable alternatives such as biocontrol agents, plant extracts, and nano-based postharvest technologies [69, 70].

Conclusion

This study comprehensively revealed the physiological, biochemical, and antioxidant effects of various substances such as LPE, citric acid, sucrose, and streptomycin added to vase solutions in cut *Gerbera jamesonii* flowers. The applied substances caused significant differences in important quality parameters such as water uptake, fresh weight change, and vase life, as well as in the levels of oxidative stress markers such as SOD, POD, CAT, APX, and MDA. The most successful results in the study were obtained with the T9 and T10 treatments. In particular, the T10 treatment (2 ppm LPE + 200 mg L^{-1} streptomycin + 200 mg L^{-1} citric acid + 5% sucrose) stood out with high water uptake, long vase life, and the lowest MDA level. It was observed that POD activity increased significantly in high-dose LPE treatments (T6 (2 ppm LPE), T7 (4 ppm LPE)), but the parallel increase in MDA levels revealed that LPE alone could increase oxidative stress. The potential effect of citric acid treatment on CAT activity is important in terms of the detoxification of reactive oxygen species such as hydrogen peroxide. Additionally, the increase in levels of secondary metabolites such as phenolic compounds, flavonoids, and anthocyanins has been an important indicator of the defense mechanisms developed by the plant against oxidative stress during the aging process. Overall, it has been determined that combination treatments (especially T9 (1 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar), T10 (2 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar), T11 (4 ppm LPE + 200 mg L^{-1} Streptomycin + 200 mg L^{-1} Citric acid + 5% Sugar)) have more positive effects on both morphological and biochemical parameters compared to single treatments. The synergistic use of substances such as streptomycin, LPE, citric acid, and sucrose is proposed as an effective approach for extending the vase life of cut flowers, improving water relations, and reducing oxidative stress. This study has revealed important findings that could contribute to the development of new solution formulations aimed at preserving the postharvest quality of cut flowers. Our findings suggest that LPE, particularly when used in combination with streptomycin, may offer practical potential for the ornamental plant sector by extending vase life and reducing post-harvest losses. Given its relatively low cost and ability to be integrated into protective solutions, LPE could provide an economically viable and environmentally friendly approach to cut flower management.

Abbreviations

STS	Silver Thiosulfate
RFW	Relative Fresh Weight
DVSU	Daily Vase Solution Uptake
WSt-1	Previous Day Weight of Vase Solution
WSt	Weight of Vase Solution on Day t (2, 4, 6, etc.)
Wt	Stem weight at day t (2, 4, 6, etc.)
Wt0	Stem weight at day 0
TVSU	Total Vase Solution Uptake
NA	Nutrient Agar
NaCl	Sodium Chloride
POD	Peroxidase
SOD	Superoxide Dismutase
MDA	Malondialdehyde

Acknowledgements

This study was produced by the Scientific and Technological Research Council of Turkey within the scope of '2218 - Domestic Postdoctoral Research Fellowship Program' Project No. 123C133. We would like to thank the Scientific and Technological Research Council of Turkey for its contributions.

Authors' contributions

OSA : Visualization, Conceptualization, Methodology, Data analyzing, Supervision, Writing - original draft, Review, and editing. **OS** : Methodology, Supervision, Review, and editing.

Funding
This study was supported by the Scientific and Technological Research Council of Turkey (123C133).

Data availability
Data will be available on request to the corresponding authors.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 12 July 2025 / Accepted: 13 October 2025
Published online: 05 December 2025

References

1. Rakbar S, Jabbarzadeh Z, Barin M. Impact of putrescine and arbuscular mycorrhizal fungi on nutrient uptake, growth, and post-harvest performance of *Gerbera jamesonii* cv. dune) cut flowers. Acta Physiol Plant. 2024;46(4):45. https://doi.org/10.1007/s11738-024-03674-4.
2. Ali IA, Hassan SE, Abdelhafez AA, Hewidy M, Nasser MA, Saudy HS, et al. Modifying the growing media and bio stimulants supply for healthy *Gerbera jamesonii* flowers. J Crop Health. 2024;76(1):337–45. https://doi.org/10.1007/s10343-023-00943-z.
3. Singh P, Bhardwaj A, Kumar R, Singh D. Evaluation of Gerbera varieties for yield and quality under protected environment conditions in Bihar. Int J Curr Microbiol Appl Sci. 2017;6(9):112–6. https://doi.org/10.20546/ijcmas.2017.609.013.
4. Deng ZH, Bhattarai K. Chapter 17. Gerbera. University of Florida. IFAS, Department of Environmental Horticulture, Gulf Coast Research; 2018.
5. Zhou Y, Yin M, Abbas F, Sun Y, Gao T, Yan F, et al. Classification and association analysis of Gerbera (*Gerbera hybrida*) flower color traits. Front Plant Sci. 2022;12:779288. https://doi.org/10.3389/fpls.2021.779288.
6. Onozaki T. Breeding of carnations (*Dianthus caryophyllus* L.) for long vase life. Breed Sci. 2018;68:3–13. https://doi.org/10.1270/jsbbs.17091.
7. Shibuya K. Molecular aspects of flower senescence and strategies to improve flower longevity. Breed Sci. 2018;68:99–108. https://doi.org/10.1270/jsbbs.17081.
8. Woltering EJ, Van Doorn WG. Role of ethylene in senescence of petals—morphological and taxonomical relationships. J Exp Bot. 1988;39:1605–16. https://doi.org/10.1093/jxb/39.11.1605.
9. Tonooka M, Homma Y, Nukui H, Ichimura K. The effects of bacteria in vase water on the vase life of cut Gerbera cultivars. Hort Res (Japan). 2019;18:167–72.
10. Perik RRJ, Razé D, Harkema H, Zhong Y, Van Doorn WG. Bending in cut *Gerbera jamesonii* flowers relates to adverse water relations and lack of stem sclerenchyma development, not to expansion of the stem central cavity or stem elongation. Postharvest Biol Technol. 2012;74:11–8. https://doi.org/10.1016/j.postharvbio.2012.06.009.
11. Perik RRJ, Razé D, Ferrante A, Van Doorn WG. Stem bending in cut *Gerbera jamesonii* flowers: effects of a pulse treatment with sucrose and calcium ions. Postharvest Biol Technol. 2014;98:7–13. https://doi.org/10.1016/j.postharvbio.2014.06.008.
12. Tonooka M, Homma Y, Toyoizumi T, Ichimura K. Stem bending in cut *Gerbera* under the condition of suppressing bacterial proliferation is associated with the weakening of the stem strength. Sci Hortic. 2023;319:112153. https://doi.org/10.1016/j.scienta.2023.112153.
13. Zulfiqar F, Al-Huqail AA, Alghanem SMS, Alsudays IM, Moosa A, Chen J, et al. Ascorbic acid increases cut flower longevity of sword lily by regulating oxidative stress and reducing microbial load. J Plant Growth Regul. 2024;(11):11. https://doi.org/10.1007/s00344-024-11396-7.
14. de Witte Y, Harkema H, Van Doorn WG. Effect of antimicrobial compounds on cut Gerbera flowers: poor relation between stem bending and numbers of bacteria in the vase water. Postharvest Biol Technol. 2014;91:78–83. https://doi.org/10.1016/j.postharvbio.2013.12.018.
15. Faragher JD, Borochov A, Keren-Paz V, Adam Z, Halevy AH. Changes in parameters of cell senescence in carnation flowers after cold storage. Sci Hortic. 1984;22(3):295–302. https://doi.org/10.1016/0304-4238(84)90063-3.
16. Faragher JD, Mayak S, Tirosh T. Physiological response of cut rose flowers to cold storage. Physiol Plant. 1986;67(2):205–10. https://doi.org/10.1111/j.1399-3054.1986.tb02444.x.
17. Goszczyńska DM, Rudnicki RM. Storage of cut flowers. Hortic Rev. 1988;10:35–62. https://doi.org/10.1002/9781118060834.ch2.
18. Cevallos JC, Reid MS. Effects of temperature on the respiration and vase life of narcissus flowers. Acta Hortic. 2000;517:335–41. https://doi.org/10.17660/ActaHortic.2000.517.42.
19. Çelikel FG, Reid MS. Storage temperature affects the quality of cut flowers from the Asteraceae. HortScience. 2002;37(1):148–50. https://doi.org/10.21273/HORTSCI.37.1.148.
20. Reid MS, Jiang CZ. Postharvest biology and technology of cut flowers and potted plants. Hortic Rev. 2012;40:1–54. https://doi.org/10.1002/9781118351871.ch1.
21. Reid MS. Postharvest handling systems: Ornamental crops. In: Kader AA, editor. Postharvest Technology of Horticultural Crops. St Davis, CA: Univ of California, Agriculture and Natural Resources; 2002. p. 315–25 ISBN 1879906511.
22. Jahnke NJ, Kalinowski J, Dole JM. Postharvest handling techniques for long-term storage of cut tulip and Dutch Iris. HortTechnology. 2022;32(3):263–74. https://doi.org/10.21273/HORTTECH05010-21.
23. van Doorn WG, Stead AD. Abscission of flowers and floral parts. J Exp Bot. 1997;48(4):821–37. https://doi.org/10.1093/jxb/48.4.821.
24. Waters M, Tadi P. Streptomycin. In: StatPearls. Treasure Island (FL): Stat Pearls Publishing; 2022. https://www.ncbi.nlm.nih.gov/books/NBK555886/.
25. Waksman SA. Streptomycin: background, isolation, properties, and utilization. Science. 1953;118(3062):259–66. https://doi.org/10.1126/science.118.3062.259.
26. Maillard JY. Bacterial target sites for biocide action. J Appl Microbiol. 2002;92:S16–27. https://doi.org/10.1046/j.1365-2672.92.5s1.3.x.
27. Özgen M, Serçe S, Akça Y, Hong JH. Lysophosphatidylethanolamine (LPE) improves fruit size, color, quality, and phytochemical contents of sweet Cherry Cv '0900 ziraat.' Hortic Sci Technol. 2015;33(2):196–201. https://doi.org/10.7235/hort.2015.13195.
28. Farag KM, Palta JP. Use of natural lipids to accelerate ripening and enhance storage life of tomato fruit with and without ethephon. HortTechnology. 1993;3:62–5. https://doi.org/10.21273/HORTTECH.3.1.62.
29. Özgen M, Farag KM, Özgen S, Palta JP. Lysophosphatidylethanolamine accelerates color development and promotes shelf life of cranberries. HortScience. 2004;40:127–30. https://doi.org/10.21273/HORTSCI.40.1.127.
30. Farag KM, Palta JP. Use of lysophosphatidylethanolamine, a natural lipid, to retard tomato leaf and fruit senescence. Physiol Plant. 1993;87:515–24. https://doi.org/10.1111/j.1399-3054.1993.tb02501.x.
31. Kaur N, Palta JP. Postharvest dip in a natural lipid, lysophosphatidylethanolamine, may prolong vase life of snapdragon flowers. HortScience. 1997;32:888–90. https://doi.org/10.21273/HORTSCI.32.5.888.
32. Cowan AK. Plant growth promotion by 18:0-lyso-phosphatidylethanolamine involves senescence delay. Plant Signal Behav. 2009;4:324–7. https://doi.org/10.4161/psb.4.4.8188.
33. Hong JH, Chung GH, Cowan AK. Delayed leaf senescence by exogenous lysophosphatidylethanolamine: towards a mechanism of action. Plant Physiol Biochem. 2009;47:526–34. https://doi.org/10.1016/j.plaphy.2008.12.014.
34. Çeler AG, Gündüz K, Serçe S. Effect of lysophospathidylethanolamine (LPE) for strawberry Pomological and phytochemical quality characteristics during storage. Mustafa Kemal Univ Tarim Bilim Derg. 2019;24(3):188–97.
35. Kaur N, Palta JP. Prolonging the vase life of snapdragons and carnations with a natural Lipid, lysophosphatidylethanolamine (LPE). HortScience. 1996;31:4636–637.
36. Snider A, Palta JP, Peoples T. The potential use of lysophosphatidylethanolamine (LPE), a natural lipid, to lengthen the vase life of short-lived 'Lavande' and 'Sensation' roses. In XXVI International Horticultural Congress: Elegant Science in Floriculture. 2002:624,419–426. https://doi.org/10.17660/ActaHortic.2003.624.59.
37. Kaur N, Palta JP. Postharvest dip in a natural lipid, lysophosphatidylethanolamine, May prolong vase life of snapdragon flowers. HortScience. 1997;32:5888–890. https://doi.org/10.21273/HORTSCI.32.5.888.

38. Gerasopoulos D, Chebli B. Effects of pre-and postharvest calcium applications on the vase life of cut Gerberas. J Hortic Sci Biotech. 1999;74(1):78–81. https://doi.org/10.1080/14620316.1999.11511076.
39. Singleton VL, Rossi JA. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. Am J Enol Vitic. 1965;16(3):144–58. https://doi.org/10.5344/ajev.1965.16.3.144.
40. Zhishen J, Mengcheng T, Jianming W. The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. Food Chem. 1999;64(4):555–9. https://doi.org/10.1016/S0308-8146(98)00102-2.
41. Ozgen M, Reese RN, Tulio AZ, Scheerens JC, Miller AR, Modified. 2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) method to measure antioxidant capacity of selected small fruits and comparison to ferric reducing antioxidant power (FRAP) and 2, 2 '-diphenyl-1-picrylhydrazyl (DPPH) methods. J Agric Food Chem. 2006;2(4):1151–7. https://doi.org/10.1021/jf051960d.
42. Giusti MM, Wrolstad RE. Characterization and measurement of anthocyanins by UV-visible spectroscopy. In: Wrolstad RE, Schwartz SJ, editors. Handbook of food analytical chemistry. New York: Wiley; 2005. pp. 19–31. https://doi.org/10.1002/0471142913.faf0102s00.
43. He Y, Qian L, Liu X, Hu R, Huang M, Liu Y, et al. Graphene oxide as an antimicrobial agent can extend the vase life of cut flowers. Nano Res. 2018;11:6010–22. https://doi.org/10.1007/s12274-018-2115-8.
44. Aremu OS, Qwebani-Ogunleye T, Katata-Seru L, Mkhize Z, Trant JF. Synergistic broad-spectrum antibacterial activity of *Hypoxis hemerocallidea*-derived silver nanoparticles and streptomycin against respiratory pathobionts. Sci Rep. 2021;11:1–11. https://doi.org/10.1038/s41598-021-93978-z.
45. Al-Humaid AI. Effect of glucose and biocides on vase-life and quality of cut gladiolus spikes. In V International Postharvest Symposium. 2004;682:519–526. https://doi.org/10.17660/ActaHortic.2005.682.64.
46. Change B, Maehly AC. Assay of catalases and peroxidase. Methods Enzymol. 1955;2764–775. https://doi.org/10.1016/S0076-6879(55)02300-8.
47. Pourzarnegar F, Hashemabadi D, Kaviani B. Cerium nitrate and salicylic acid on vase life, lipid peroxidation, and antioxidant enzymes activity in cut Lisianthus flowers. Ornam Hortic. 2020;26:658–69. https://doi.org/10.1590/2447-536X.v26i4.2227.
48. Jebara S, Jebara M, Limam F, Aouani ME. Changes in ascorbate peroxidase, catalase, Guaiacol peroxidase and superoxide dismutase activities in common bean (Phaseolus vulgaris) nodules under salt stress. J Plant Physiol. 2005;162:829–936. https://doi.org/10.1016/j.jplph.2004.10.005.
49. Güneri Bağcı E. Nohut Çesitlerinde Kuraklıkga Bağlı Oksidatif Stresin Fizyolojik ve Biyokimyasal Parametrelerle Belirlenmesi (Doktora Tezi). Ankara Univ Hekim Fak. 2010:403.
50. Nair PMG, Chung IM. Study on the correlation between copper oxide nanoparticles induced growth suppression and enhanced lignification in Indian mustard (*Brassica juncea* L). Ecotoxicol Environ Saf. 2015;113:302–13. https://doi.org/10.1016/j.ecoenv.2014.12.013.
51. Çelikel FG, Reid MS, Jiang CZ. Postharvest physiology of cut *Gardenia jasminoides* flowers. Sci Hortic. 2020;261:108983. https://doi.org/10.1016/j.scienta.2019.108983.
52. Li HB, Li HM, Liu J, Luo Z, Joyce DC, He S. Nano-silver treatments reduced bacterial colonization and biofilm formation at the stem-ends of cut gladiolus 'Eerde' spikes. Postharvest Biol Technol. 2017;123:102–11. https://doi.org/10.1016/j.postharvbio.2016.08.014.
53. Damunupola JW, Joyce DC. When is a vase solution biocide not, or not only, antimicrobial? J Jpn Soc Hortic Sci. 2008;77:211–28. https://doi.org/10.2503/jjshs1.77.211.
54. Faragher J, Gollnow B, Joyce D. Postharvest handling of Australian flowers from Australian native plants and related species: a practical manual. Postharvest handling of Australian flowers from Australian native plants and related species: a practical manual. (Ed. 2). 2010.
55. de Carvalho APA, Conte-Junior CA. Nanoencapsulation application to prolong postharvest shelf life. Curr Opin Biotechnol. 2022;78:102825. https://doi.org/10.1016/j.copbio.2022.102825.
56. SeyedHajizadeh H, FarajiChelanolya A, Zahedi SM, Moghadam A, Mahdavinia G, Kaya O. Nanochitosan-encapsulated melatonin: an eco-friendly strategy to delay petal senescence in cut *Gerbera* flowers. BMC Plant Biol. 2024;24(1):1024. https://doi.org/10.1186/s12870-024-05725-x.
57. Kazaz S. Kesme Çiçeklerde Hasat Sonrası Ömrü Etkileyen Faktörler. Türkiye Tohumcular Birliği Dergisi. 2015;14:42–6.
58. Li HM, Huang X, Li J, Liu J, Joyce DC, He S. Efficacy of nano-silver in alleviating bacteria-related blockage in cut rose cv. movie star stems. Postharvest Biol Technol. 2012;74:36–41. https://doi.org/10.1016/j.postharvbio.2012.06.013.
59. Ratnayake K, Joyce DC, Webb RI. A convenient sample preparation protocol for scanning electron microscope examination of xylem-occluding bacterial biofilm on cut flowers and foliage. Sci Hortic. 2012;140:12–8. https://doi.org/10.1016/j.scienta.2012.03.012.
60. Stockwell VO, Moore LW, Loper JE. Fate of Agrobacterium radiobacter K84 in the environment. Appl Environ Microbiol. 1993;59:2112–20. https://doi.org/10.1128/aem.59.7.2112-2120.1993.
61. Zhou J, Dong Y, Zhao X, Lee S, Amin A, Ramaswamy S, et al. Selection of antibiotic-resistant bacterial mutants: allelic diversity among fluoroquinolone-resistant mutations. J Infect Dis. 2000;182:517–25. https://doi.org/10.1086/315708.
62. Bleeksma HC, Van Doorn WG. Embolism in Rose stems as a result of vascular occlusion by bacteria. Postharvest Biol Technol. 2003;29:335–41. https://doi.org/10.1016/S0925-5214(03)00049-8.
63. Carlson AS, Dole JM, Matthysse AG, Hoffmann WA, Kornegay JL. Bacteria species and solution pH effect postharvest quality of cut *Zinnia elegans*. Sci Hortic. 2015;194:71–8. https://doi.org/10.1016/j.scienta.2015.07.044.
64. Naing AH, Win NM, Han JS, Lim KB, Kim CK. Role of nano-silver and the bacterial strain Enterobacter cloacae in increasing vase life of cut carnation 'Omea.' Front Plant Sci. 2017;8:1590. https://doi.org/10.3389/fpls.2017.01590.
65. Wang H, Zhang Y, Song Y, Zhu J, Shang W, Jiang L, et al. ClO_2 prolongs the vase life of *Paeonia lactiflora* 'Hushui dangxia'cut flowers by inhibiting bacterial growth at the stem base. Horticulturae. 2024;10:7732. https://doi.org/10.3390/horticulturae10070732.
66. Apel K, Hirt H. Reactive oxygen species: metabolism, oxidative stress, and signal transduction. Annu Rev Plant Biol. 2004;55(1):373–99. https://doi.org/10.1146/annurev.arplant.55.031903.141701.
67. McManus PS, Stockwell VO, Sundin GW, Jones AL. Antibiotic use in plant agriculture. Annu Rev Phytopathol. 2002;40:443–65. https://doi.org/10.1146/annurev.phyto.40.120301.093927.
68. Sundin GW, Wang N. Antibiotic resistance in plant-pathogenic bacteria. Annu Rev Phytopathol. 2018;56:1. https://doi.org/10.1146/annurev-phyto-080417-045946.
69. Compant S, Samad A, Faist H, Sessitsch A. A review on the plant microbiome: ecology, functions, and emerging trends in microbial application. J Adv Res. 2019;19:29–37. https://doi.org/10.1016/j.jare.2019.03.004.
70. Lawal H, Gaddafi MS, Jamiu AM, Edo GS, Fremah OG, El-Yakub AU, et al. Biocontrol and nanotechnology strategies for postharvest disease management in fruits and vegetables: a comprehensive review. Foods. 2025;14:162782. https://doi.org/10.3390/foods14162782.
71. Zeng CL, Liu L, Xu GQ. The physiological responses of carnation cut flowers to exogenous nitric oxide. Sci Hortic. 2011;127:424–30. https://doi.org/10.1016/j.scienta.2010.10.024.
72. He S, Joyce DC, Irving DE, Faragher JD. Stem end blockage in cut grevillea 'Crimson yullo' inflorescences. Postharvest Biol Technol. 2006;41:78–84. https://doi.org/10.1016/j.postharvbio.2006.03.002.

Publisher's Note