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OPTIMIZING POSTHARVEST HANDLING PROTOCOLS FOR CUT *Helianthus annuus* L. - A NOVEL SPECIALTY CUT FLOWER

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ABSTRACT

Research was conducted to assess the response of *Helianthus annuus* L. (sunflower) to various postharvest handling procedures for optimizing suitable protocols and ensuring the longest possible vase life. Experiments were conducted to optimize the harvest stage, harvest time, handling procedures, vase water quality, pulsing preservatives and vase preservatives. For harvest stage, partially opened flowers had the longest vase life (7.5 d), followed by stems harvested at closed bud stage (6.5 d). For harvest time, stems harvested in evening had longest vase life (7.6 d). For handling procedure, longest vase life (7.1 d) was recorded in wet-wet (continuously) hydrated throughout handling, succeeded by dry-wet handled stems (5.4 d). For water quality, 5% sucrose with distilled water had longest vase life (8.2 d). For storage methods and durations, stems that were not stored had the longest vase life, while the stems that were stored had the shorter vase life. For pulsing solutions, stems pulsed with Chrysal Clear Universal flower food had the longest vase life (11.6 d). In vase preservatives, Floralife flower food demonstrated the most prolonged vase longevity (12.8 d), closely succeeded by Chrysal Clear Universal flower food (12.6 d). In summary, for sunflower postharvest longevity, stems should be harvested in the evening at partially opened stage and should be placed in water immediately. Moreover, stems may be pulsed with 5% sucrose and for vase solutions, stems should be placed in Commercial preservatives, such as Floralife flower food or Chrysal Clear Universal flower food or homemade solutions, such as lemon/lime soda + distilled water (50:50) for longest vase life.

Keywords: Commercial preservatives, electrolyte leakage, storage, sunflower, vase life.

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INTRODUCTION

The longevity of cut flowers is a pivotal factor of consumer satisfaction and economic success in floriculture business. Short postharvest life is also one of the greatest challenges that florists, growers and marketing stakeholders are facing since quick senescence is decreasing the aesthetic quality, market value and profitability. Cut flowers are also perishable products by nature, and their postharvest behavior is determined by a complicated combination of genetic, physiological, environmental, and handling related factors (Kumar *et al*., 2024). Enhancing postharvest life by using optimal handling methods is thus vital to maintain competitiveness and postharvest losses in commercial floriculture.

The postharvest life of cut flowers is governed by several preharvest and postharvest determinants, including genotype, cultivation conditions, duration of the growing season, environmental stresses, harvest stage, harvest time and postharvest handling procedures (Moura *et al*., 2022). Among these, harvest stage is particularly crucial, as it directly influences flower opening, visual appeal, and vase life. Flowers harvested at an inappropriate developmental stage may fail to open properly or senesce rapidly, leading to reduced marketability. Likewise, harvest timing plays a significant role, as diurnal fluctuations in temperature, relative humidity, and plant water status affect turgor and carbohydrate reserves. Generally, harvesting during cooler periods of the day, such as early morning or evening, minimizes heat stress and water loss, thereby enhancing postharvest quality.

Postharvest handling practices further determine the ability of cut flowers to maintain water balance and physiological integrity. Cut flowers are highly sensitive to desiccation and even brief exposure to unfavorable handling conditions can induce irreversible damage (Reid, 2012). The decision to handle stems under wet or dry conditions immediately after harvest influences

subsequent water uptake and vase performance. While some species, such as marigold (*Tagetes erecta* L.) and rose (*Rosa* L.), exhibit tolerance to dry handling without significant quality loss (Ahmad *et al*., 2012; Macnish *et al*., 2009), many cut flowers rapidly develop negative water balance when deprived of water. This imbalance may lead to xylem blockage caused by bacterial proliferation, cellular debris, or air embolism, ultimately reducing hydraulic conductivity and accelerating senescence. Extended exposure of cut stems to air can also result in cavitation and embolism due to the entry of atmospheric gases through the cut stem ends. Reduced water uptake leads to diminished turgor pressure, increased water stress, and premature wilting. In addition to microbial blockage, physiological aging and mechanical damage can further exacerbate water stress, emphasizing the importance of proper hydration and sanitation during postharvest handling.

Cold storage represents another key component of postharvest management, as low temperatures and high relative humidity slow respiration, delay senescence and reduce microbial growth. Typically, cut flowers are stored at 1-4°C, although optimal storage temperature and duration vary among species and intended market use. Improper storage conditions or extended storage periods may negatively affect vase life by intensifying physiological deterioration and water imbalance. Floral preservatives are widely used to extend the longevity of cut flowers. These formulations commonly contain carbohydrates, acidifiers, biocides and other functional additives designed to enhance water uptake, inhibit microbial growth and delay senescence. Sucrose serves as an energy source, supporting respiration and flower opening, while acidifiers such as citric or acetic acid lower solution pH, thereby reducing microbial proliferation and xylem blockage. Biocides further suppress bacterial growth and ethylene inhibitors may be included to mitigate ethylene-induced senescence. However, excessive or inappropriate concentrations of chemical additives can exert phytotoxic effects and compromise flower quality (Khan *et al*., 2007). Moreover, not all cut flower species respond similarly to preservative formulations, underscoring the need for species-specific optimization.

Sunflower (*Helianthus annuus* L.) has gained increasing popularity as a specialty cut flower due to its vibrant appearance, versatility in floral arrangements and growing consumer demand. Despite its commercial importance, sunflower is often characterized by relatively short vase life and sensitivity to postharvest handling conditions. Existing literature on postharvest management of cut sunflowers remains limited, particularly under local agro-climatic conditions. Comprehensive studies integrating harvest stage, harvest timing, handling methods, water quality, storage strategies and preservative formulations are scarce, creating a critical knowledge gap for growers and florists. Therefore, the present study was undertaken to develop evidence-based postharvest handling protocols for cut sunflower aimed at maintaining stem quality and maximizing vase life. By systematically evaluating the effects of harvest stage, harvest time, handling procedures, vase water quality, storage methods and durations, and preservative solutions, this study seeks to identify optimal combinations that enhance postharvest longevity. The findings are expected to contribute to improved quality, extended vase life, increased economic returns, and sustainable postharvest practices. It was hypothesized that the optimization of postharvest handling protocols would significantly improve the vase performance of cut sunflower, benefiting growers, florists and other stakeholders across the floriculture value chain.

MATERIALS AND METHODS

Plant material and experimental design: A study was performed at the Commercial Floriculture Laboratory, Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan, during 2023-24. In this study, seven postharvest experiments were conducted to optimize the best harvest stage, harvest time, handling procedure, vase water quality, storage methods and durations as well as the effect of pulsing and vase preservatives on quality and vase life of cut 'Vincent Choice' sunflower stems. Stems were grown in open field following standard commercial procedures and harvested at a partially opened stage (when ray florets were oriented perpendicularly to disc florets) unless specified otherwise, from the Floriculture Research Area, Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan, prior to 09:00 AM, subsequently placed in containers filled with tap water, brought to the lab. within an hour of harvest and subsequently hydrated for two hours in the laboratory prior to the commencement of experiments. Afterwards, stems were sorted into groups according to stem length, stem diameter and stage of development, and distributed randomly in all treatments having uniform stem quality. Stems were labeled and re-cut to uniform stem length of 60 cm unless otherwise indicated. For each experiment, solutions were freshly prepared utilizing distilled water; unless specified otherwise, the pH level and electrical conductivity (EC) of the water were maintained at 4.0 and 0.00 µS cm^{-1}, respectively. Following the implementation of the treatments, stems were carefully placed in containers holding 600 mL of distilled water, with two stems designated per container and five replications per treatment. Containers were randomized in completely randomized design except for storage trial, which was randomized in CRD with factorial arrangements. Stems were kept in a controlled postharvest laboratory environment maintained at a

temperature of 22 ± 2°C, in conjunction with a relative humidity of 60 ± 10% and a photosynthetic photon flux density that varied from 8 to 12 µmol $m^{-2}s^{-1}$, provided at bench level by white fluorescent tubes for a daily photoperiod extending over 12 hours (Ahmad *et al*., 2014).

Harvest stage: Stems were taken at three distinct stages, viz. closed bud stage, partially opened stage (when ray florets were in perpendicular position to disc florets), or fully opened flower stage (Fig. 1). This experiment was laid out according to completely randomized design (CRD) with five replications of two stems each.

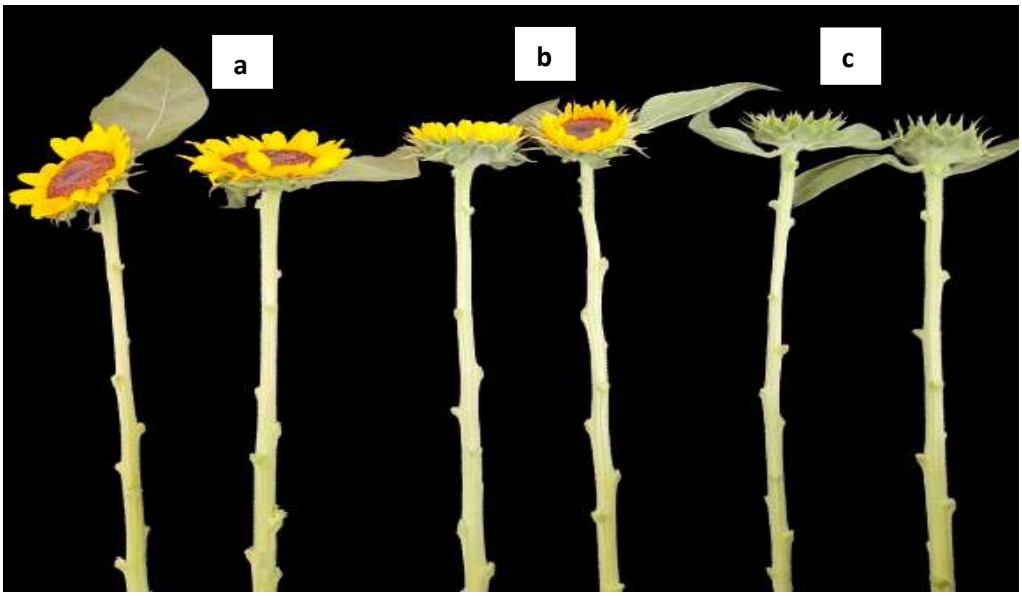

Fig. 1. Different harvest stages for sunflower used in harvest stage experiment: (a) Fully opened stage, (b) Partially opened stage, and (c) Closed bud stage.

Harvest time: Stems were harvested at three distinct times of day, viz. morning (08:00 – 09:00 AM), noon (12:00 – 01:00 PM), evening (5:00-6:00 PM). Experiment was laid out according to CRD with five replications of two stems each.

Handling procedures: Stems were excised from the plants in the morning prior to 09:00 AM; half were placed in a container of tap water, while the other half were stored in a dry cardboard box. After an hour, fifty percent of the wet stems from the bucket were moved to the cardboard box, thereby retaining the remaining other fifty percent in the bucket with water. Likewise, fifty percent of the stems from the cardboard box were relocated to the bucket with water, resulting in retention of the remaining fifty percent within the cardboard box (desiccated) for another hour. After being labeled and recut to a consistent 60-cm stem length, the stems were put in glass jars for analysis. The experiment was laid out according to CRD with five replications of two stems each.

Vase water quality: Stems were harvested in the morning before 09:00 AM, put immediately in buckets with water, transported to the lab. within an hour of harvest and given two hours to hydrate. Afterwards, stems were pulsed with 2% or 5% sucrose for 24 hours followed by shifting in the jars containing tap, canal and distilled water according to the treatments until termination and evaluated. The experiment was laid out according to CRD with five replications of two stems each.

Pulsing Preservatives: The stems were subjected to processing as delineated above and upon their arrival at the laboratory, they underwent a pulsing treatment with various solutions including 2% sucrose, 5% sucrose, 2% sucrose combined with 300 mg L^{-1} citric acid, 2% sucrose in conjunction with 200 mg L^{-1} salicylic acid, 2% sucrose alongside 200 mg L^{-1} aluminum sulphate, 2% sucrose mixed with 6 mL L^{-1} lemon juice, a 66:33 mixture of lemon/lime soda and distilled water, two tablets of aspirin per liter water, Chrysal Clear Universal flower food, and a combination of 2% sucrose with 100 mg L^{-1} gibberellic acid, 100 mg L^{-1} benzyl adenine, and 100 mg L^{-1} citric acid, or alternatively distilled water (control) for a duration of 24 hours. Afterwards, stems were shifted to containers containing 600 mL distilled water until termination and evaluated. The experiment was laid out according to CRD with five replications of two stems each.

Vase preservatives: Upon transfer to the laboratory environment, stems were maintained in various solutions including distilled water, 1% sucrose solution combined with 150 mg L^{-1} of citric acid, 1% sucrose solution with

100 mg L^{-1} of salicylic acid, 1% sucrose solution containing 100 mg L^{-1} of aluminum sulfate, 1% sucrose solution supplemented with 4 mL L^{-1} of lemon juice, 1% sucrose solution mixed with 15 mL L^{-1} of bleach, 50:50 mixture of lemon/lime soda and distilled water, 1% sucrose solution mixed with 4 mL L^{-1} vinegar, as well as Floralife Crystal Clear flower food or Chrysal Clear Universal flower food until the conclusion of the experiment. The experiment was laid out according to completely randomized design (CRD) with five replications of two stems each.

Storage methods and durations: With the exception of the control treatment stems, which were put straight into vases with 600 mL of distilled water in a postharvest evaluation room without storage, stems were harvested during the morning hours, recut to a length of 65 cm, appropriately labeled and subsequently stored either in standard cardboard floral boxes lined with newspaper or in buckets filled with tap water, while being maintained in a cold storage at a temperature of 4 ± 1°C. Stems were kept wet or dry for 1, 2, or 3 days. Afterwards, stems were shifted to the laboratory at 24-hr interval and recut removing the lower 4 to 5 cm and placed in containers containing 600 mL of distilled water, with two stems per container and assessed until termination. The experiment was arranged in a CRD with factorial layout, with five replications, each consisting of two stems.

Measurements: Data were collected daily for vase life (time span between placing stems in vases in the postharvest evaluation room and when individual stems were terminated), change in solution pH and EC (µS cm^{-1}), fresh weight change (g) was recorded using digital electric balance (Model, AFD 4000) by subtracting final fresh weight (W_1) from initial fresh weight (W_0) (recorded at day 0). The initial fresh weight was meticulously documented prior to the placement of stems into glass containers, and the final fresh weight was subsequently recorded on the termination date, from which their average was calculated. Stem quality was evaluated on the fifth day by three judges utilizing a rating scale range of 1 to 9 (9 denotes superior quality; 5 signifies average quality and 1 indicates inferior quality) (Cooper and Spokas, 1991). Water uptake (mL) was recorded using measuring cylinder by measuring the water remaining in jar and subtracting it from initial volume (600 mL), from each jar when 25% of the stems in the experiment were terminated. A digital electric balance (Model: AFD 1000) was used to measure the dry weight of the stems after the samples were dried in the shade followed by oven drying for 72 hours at a constant temperature of 70°C.

At termination, when five new ray florets were randomly chosen from each replication and rubbed with sand, electrolyte leakage (%) was measured. The rubbed petals were placed in test tubes with 15 mL of distilled water after being thoroughly cleaned with it. EC_1 was measured 10 minutes after these test tubes were placed on an orbital shaker. Test tubes were put on the orbital shaker for another hundred minutes. Electrolyte leakage was calculated using the following formula once EC_2 was recorded:

Electrolyte leakage (%) = $EC_2/EC_1 \times 100$

For termination symptoms, viz. petal wilt, stem bending, stem necrosis, leaf necrosis, leaf wilt, fungal attack and stem dilution/ rottening disorder, were recorded as either present or not on each stem. Stems were considered ready to terminate when they exhibited >50% of any above-mentioned symptoms (Ahmad *et al*., 2013).

Statistical analysis: Data from all experiments were analyzed using the Statistix 8.1 statistical software. One-way or two-way analysis of variance (ANOVA) was performed as appropriate to the experimental design, and treatment means were compared using Fisher's Least Significant Difference (LSD) test at a 5% probability level (Steel *et al*., 1997).

RESULTS

Harvest stage: Partially opened stems exhibited the longest vase longevity (7.5 days), representing an extension of approximately one day relative to the closed-bud stage (6.5 days) (Table 1). This harvest stage also recorded the highest increase in fresh weight (20.8 g) and the greatest water uptake (394 mL). Regarding termination symptoms, partially opened stems showed complete leaf wilting (100%), whereas fully opened stems exhibited complete flower wilting and stem-end rotting (100% each). In contrast, closed-bud stems were characterized by the highest incidence of stem bending (100%) (Table 1).

Harvest time: Evening-harvested stems exhibited the longest vase life (7.6 days) (Table 2). In contrast, morning-harvested stems showed the greatest increase in fresh weight (31.1 g), the highest water uptake (220 mL), and the highest incidence of stem necrosis (80%). Noon-harvested stems displayed the most severe termination symptoms, with 100% flower wilting, 100% leaf wilting, and 80% stem bending (Table 2).

Handling procedure: The wet–wet treatment (day 0 to termination) resulted in the longest vase life (7 days). This treatment also produced the greatest increase in fresh weight (19.5 g) and the highest water uptake (452.5 mL). Stem necrosis was comparable between the wet–wet and wet–dry treatments (60% each), while stem rotting remained constant across all treatments (80%). The highest incidence of stem bending was observed in the wet–dry treatment (Table 3).

Vase water quality: Stems held in distilled water supplemented with 5% sucrose or 2% sucrose exhibited the greatest vase longevity (8.2 and 6.0 days, respectively) compared with those placed in canal or tap water (Fig. 2). The highest flower wilting incidence was observed in the 2% sucrose + distilled water treatment (100%), followed by 5% sucrose + distilled water (89%). Leaf necrosis was most pronounced in the 2% sucrose + tap water treatment (80%). Both 2% sucrose + distilled water and 5% sucrose + distilled water resulted in similar levels of stem bending (20%) (Fig. 2).

Table 1. Effect of different harvest stages on postharvest attributes of sunflower (*Helianthus annuus* L.). n = 10

Treatments (Harvest stages)	Vase life (days)	Change in fresh weight (g)	Water uptake (mL)	Termination symptoms			
				Flower wilt (%)	Leaf wilt (%)	Stem bending (%)	Stem end rottening (%)
Closed bud stage	6.5±0.2 ^{b}	14.2±0.3 ^{c}	320±12.6 ^{b}	20± 0.2 ^{b}	60± 0.2 ^{ab}	60±0.2 ^{ab}	20±0.2 ^{b}
Partially opened stage	7.5± 0.1 ^{a}	20.8±0.3 ^{a}	394± 12.3 ^{a}	80± 0.2 ^{a}	100±0 ^{a}	20±0.2 ^{b}	60±0.2 ^{ab}
Fully opened stage	6.0± 0.2 ^{c}	16.4±0.8 ^{b}	252±6.7 ^{c}	100±0 ^{a}	20±0.2 ^{b}	100±0 ^{a}	100±0 ^{a}
LSD value at 5%	0.6	1.1	33.6	71	56	56	56

Means with different letters in a column differ significantly from each other according to LSD test at p≤0.05.

Table 2. Effect of different harvest times on postharvest attributes of sunflower (*Helianthus annuus* L.). n =10.

Treatments (Harvest times)	Vase Life (days)	Change in fresh weight (g)	Water uptake (mL)	Termination symptoms			
				Flower wilt (%)	Leaf wilt (%)	Stem bending (%)	Stem necrosis (%)
Morning	6.9± 0.2 ^{a}	31.1±1.2 ^{a}	220±8.9 ^{b}	20±0.2 ^{b}	0±0 ^{b}	0±0 ^{b}	80±0.2 ^{a}
Noon	5.9 ±0.1 ^{b}	14.3±0.4 ^{c}	130±11.2 ^{c}	100±0 ^{a}	100±0 ^{a}	80±0.2 ^{a}	0±0 ^{b}
Evening	7.6± 0.1 ^{a}	18.8±1.0 ^{c}	284±6.5 ^{a}	80±0.8 ^{a}	40±0.2 ^{a}	40±0.2 ^{ab}	0±0 ^{b}
LSD value at 5%	0.4	2.9	28.0	50	56	56	36

Means with different letters in a column differ significantly from each other according to LSD test at p≤0.05.

Table 3. Effect of different handling procedures on postharvest attributes of sunflower (*Helianthus annuus* L.). n = 10

Treatments (Handling procedures)	Vase Life (days)	Change in fresh weight (g)	Water uptake (mL)	Stem necrosis (%)	Stem bending (%)	Stem end rottening (%)
Wet-Wet	7.1±0.1 ^{a}	19.5±0.6 ^{a}	452.5±9.6 ^{a}	60±0.2	40±0.2	80±0.2
Wet-Dry	5.3±0.1 ^{bc}	8.9±0.4 ^{c}	379.0±7.8 ^{b}	60±0.2	80±0.2	80±0.2
Dry-Wet	5.4±0.1 ^{b}	11.9±1.8 ^{bc}	305.0±13.0 ^{c}	0±0	40±0.2	80±0.2
Dry-Dry	4.6±0.4 ^{c}	14.0±0.3 ^{b}	308.0±10.6 ^{c}	0±0	20±0.2	80±0.2
LSD value at 5%	0.8	3.2	31.3	NS	NS	NS

Means with different letters in a column differ significantly from each other according to LSD test at p≤0.05.
NS = Non-significant

Pulsing preservatives: Pulsing cut stems with Chrysal Clear Universal increased vase life by 6 days compared with the control (distilled water). Stems treated with 5% sucrose and 2% sucrose + 200 mg L^{-1} salicylic acid also exhibited extended vase longevity, each by 5 days. A 24-h pulse with lemon/lime soda + distilled water (66:33) improved vase life by 3 days relative to the control. In contrast, the 2% sucrose + 6 mL L^{-1} lemon juice had detrimental effects, showing the poorest flower quality (Table 4), the highest incidence of stem-end rotting (100%) and fungal growth (66%) (Table 5), and the shortest vase life (6 days). Complete flower wilting (100%) was recorded in the 5% sucrose treatment. The greatest increases in fresh weight were observed in stems treated with 5% sucrose (43.7 g) and 2% sucrose + 200 mg L^{-1} aluminum sulphate (43.2 g). The highest water uptake was also associated with 2% sucrose + 200 mg L^{-1} aluminum sulphate. The largest change in electrical conductivity (EC) occurred in the treatment containing 2% sucrose + 100 mg L^{-1} GA + 100 mg L^{-1} BA + 100 mg L^{-1} citric acid, whereas the highest pH was recorded in 2% sucrose + 200 mg L^{-1} salicylic acid. Maximum electrolyte leakage was observed in lemon/lime soda + distilled water (66:33) and 2% sucrose + two aspirin tablets, measuring 175% and 156%, respectively.

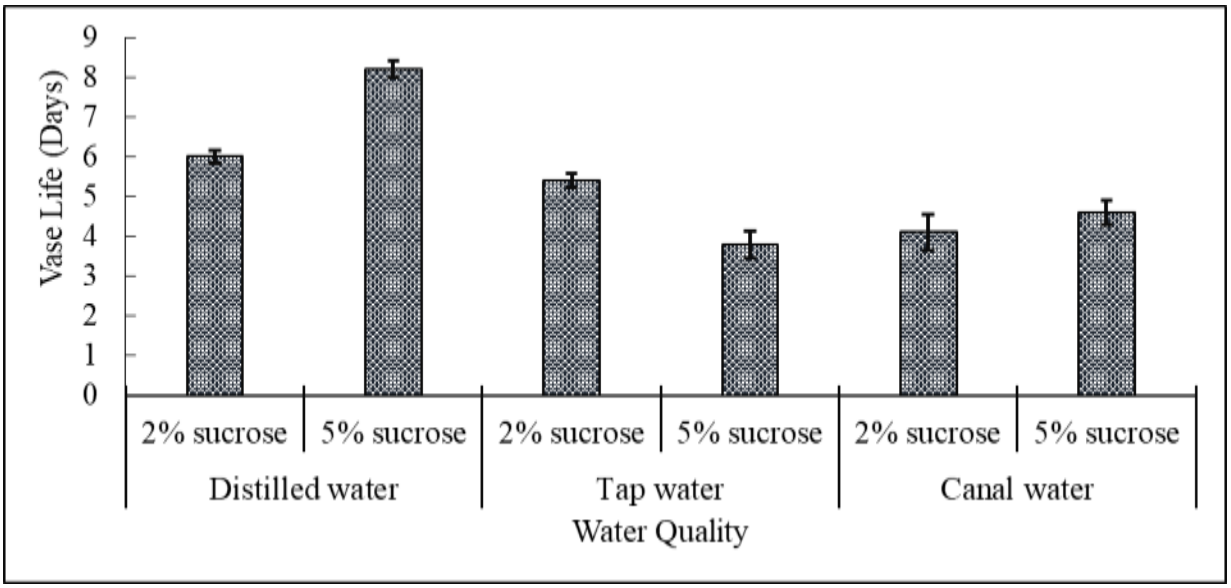

Fig. 2. Effect of vase water quality on vase life (days) of sunflower (*Helianthus annuus* L.). All bars represent means of 10 stems ± S.E.

Table 4. Effect of different pulsing preservatives on postharvest attributes of sunflower (*Helianthus annuus* L.). n = 10.

Treatments (Pulsing preservatives)	Vase life (d)	Change in fresh weight (g)	Water uptake (mL)	Change in flower quality	Electrolyte leakage (%)	Change in pH	Change in EC (µS cm^{-1})
Distilled water (control)	6.3±0.4 ^{fgz}	13.4±1.4 ^{c}	380.0±5.7 ^{bc}	8.0±1 ^{a}	132.0±2.5 ^{cde}	0.3±0.03 ^{bc}	850.0±10 ^{cd}
2% sucrose	7.6±0.4 ^{ef}	30.8±4.3 ^{ab}	316.6±1.7 ^{cd}	6.6±0.6 ^{ab}	116.1±3.6 ^{def}	0.5±0.03 ^{b}	1013.3±24.0 ^{b}
5% sucrose	10.3±0.4 ^{ab}	43.7±1.3 ^{a}	273.3±1.3 ^{d}	4.0±0.9 ^{c}	117.0±1.5 ^{def}	0.3±0.03 ^{bc}	586.6±6.6 ^{f}
2% sucrose + 300 mg L^{-1} citric acid	8.6±0.1^{cde}	35.3±2.3 ^{ab}	383.3±1.6 ^{b}	5.0±1 ^{bc}	127.0±8.6 ^{de}	0.3±0.1 ^{bc}	706.6±12.01 ^{e}
2% sucrose + 200 mg L^{-1} salicylic acid	10.0±0.2 ^{bc}	39.1±2.0 ^{ab}	330.0±5.7 ^{bcd}	4.0±0.5 ^{c}	136.3±3.0 ^{cd}	0.8±0.03 ^{a}	690.0±5.7 ^{e}
2% sucrose + 200 mg L^{-1} aluminum sulphate	8.6±0.3 ^{cd}	43.2±1.5 ^{a}	483.3±1.6 ^{a}	6.6±0.6 ^{ab}	149.1±10.4 ^{bc}	0.4±0.05 ^{bc}	436.6±3.3 ^{g}
2% sucrose + 6 mL L^{-1} lemon juice	6.0±0.5 ^{g}	31.6±7.1 ^{ab}	383.3±1.6 ^{b}	8.0±0 ^{a}	133.3±12.0 ^{cde}	0.2±0.03 ^{c}	903.3±6.6 ^{c}
Lemon/lime soda + distilled water (66:33)	9.3±0.4 ^{bcd}	24.6±4.9 ^{bc}	300.0±5.7 ^{d}	7.3±0.6 ^{a}	175.9±3.3 ^{a}	0.2±0.01 ^{c}	733.3±36.6 ^{e}
2% sucrose + 2-tab aspirin	8.6±0.03 ^{cde}	42.4±4.9 ^{a}	386.6±1.6 ^{b}	7.3±1.2 ^{a}	157.5±3.5 ^{ab}	0.2±0.1 ^{c}	906.6±26.0 ^{c}
Chrysal Clear Universal	11.6±0.8 ^{a}	10.1±6.1 ^{c}	456.6±3.3 ^{a}	3.0±1.1 ^{c}	114.3±2.9 ^{ef}	0.2±0.1 ^{c}	823.3±36.6 ^{d}
2% sucrose + 100 mg L^{-1} GA + 100 mg L^{-1} BA + 100 mg L^{-1} citric acid	8.0±0.2 ^{de}	11.9±9.7 ^{c}	330.0 ^{bcd}	4.0±2.0 ^{c}	103.4±12.8 ^{f}	0.4±0.1 ^{bc}	1240.0±55.6 ^{a}
LSD value at 5%	1.3	15.0	18.3	3.1	2.7	0.15	20.8

Means with different letters in a column differ significantly from each other according to LSD test at p≤0.05.

Vase preservatives: Compared with the control (6.4 days), vase life was extended by 6 days in stems continuously supplied with Floralife flower food or Chrysal Clear Universal flower food (Table 6). These were followed by 1% sucrose + 100 mg L^{-1} aluminum sulphate (11 days) and distilled water + lemon/lime soda (50:50) (10.8 days). The greatest increases in fresh weight (32.2 g), water uptake (568 mL), electrical conductivity (1060 µS cm^{-1}), pH (1.7), and stem bending (50%) were also observed in the Chrysal Clear Universal. Stems held continuously in 1% sucrose + 4 mL L^{-1} vinegar and 1% sucrose + bleach exhibited the poorest flower quality (scores of 8 and 7, respectively). The highest electrolyte leakage (166%) and leaf wilting (60%) were also recorded in stems kept in the 1% sucrose + bleach. Maximum dry weight (20.6 g) occurred in stems treated with 1% sucrose + 150 mg L^{-1} citric acid (Table 6).w Complete leaf necrosis (100%) was recorded in both

Floralife flower food and 1% sucrose + 4 mL L^{-1} lemon juice. Stems placed in 1% sucrose + 4 mL L^{-1} vinegar showed the highest incidence of stem-end rotting (100%) (Table 7). The most severe fungal contamination was observed in 1% sucrose + 4 mL L^{-1} lemon juice.

Table 5. Effect of different pulsing preservatives on termination symptoms of sunflower (*Helianthus annuus* L.). n = 10.

Treatments (Pulsing preservatives)	Stem end rottening (%)	Flower wilt (%)	Leaf necrosis (%)	Fungal attack (%)
Distilled water (control)	66±0.3	33±0.3	0±0 ^{c}	0±0
2% sucrose	100±0	66±0.3	0±0 ^{c}	33±0.3
5% sucrose	100±0	100±0	0±0 ^{c}	0±0
2% sucrose + 300 mg L^{-1} citric acid	66±0.3	66±0.3	100±0 ^{a}	66±0.3
2% sucrose + 200 mg L^{-1} salicylic acid	66±0.3	33±0.3	100±0 ^{a}	0±0
2% sucrose + 200 mg L^{-1} aluminum sulphate	66±0.3	33±0.3	33±0.3 ^{ab}	33±0.3
2% sucrose + 6 mL L^{-1} lemon juice	100±0	33±0.3	0±0 ^{c}	66±0.3
Lemon/lime soda + distilled water (66:33)	66±0.3	66±0.3	0±0 ^{c}	33±0.3
2% sucrose + 2-tab aspirin	66±0.3	33±0.3	100±0 ^{a}	0±0
Chrysal Clear Universal	0±0	0±0	100±0 ^{a}	0±0
2% sucrose + 100 mg L^{-1} GA + 100 mg L^{-1} BA + 100 mg L^{-1} citric acid	100±0	33±0.3	100±0 ^{a}	33±0.3
LSD value at 5%	NS	NS	29	NS

Means with different letters in a column differ significantly from each other according to LSD test at p≤0.05.
NS= Not significant at p>0.05.

Table 6. Effect of different vase preservatives on postharvest attributes of sunflower (*Helianthus annuus* L.). n = 10.

Treatments (Vase preservatives)	Vase life (days)	Change in fresh weight (g)	Water uptake (mL)	Dry weight (g)	Change in flower quality	Electrolyte leakage (%)	Change in pH	Change in EC
Distilled water (control)	6.4±0.1 ^{fg}	11.3±2.9 ^{d}	196.0±4 ^{h}	20.6±2.1 ^{ab}	8.0±0^{a}	126.4±4.1 $^{b-d}$	0.08±0.03 ^{e}	1540.0±40 ^{a}
1% sucrose + citric acid 150 mg L^{-1}	8.4±0.2 ^{de}	17.7±0.6 ^{cd}	234.0±9.2 ^{gh}	18.5±1.4 ^{ab}	6.0±0 ^{ab}	115.9±1.3 $^{c-e}$	0.92±0.4 ^{cde}	392.0±23.5 ^{de}
1% sucrose + 100 mg L^{-1} salicylic acid	9.6±0.2 ^{cd}	30.8±3.4 ^{a}	372.0±12.4 ^{d}	17.2±1.2 ^{bc}	6.0±0 ^{ab}	134.7±4.2 ^{b}	1.34±0.5^{bcd}	560.0±81.3 ^{cd}
1% sucrose + 4 mL L^{-1} lemon juice	7.4±0.4 ^{ef}	18.0±2.4 $^{b-d}$	200.0±9.4 ^{h}	21.2±1.4 ^{a}	6.4±0.2 ^{a}	133.4±4.2 ^{bc}	0.56±0.1 ^{de}	206.0±109.1 ^{ef}
1% sucrose + 100 mg L^{-1} aluminum sulphate	11.0±0.2 ^{b}	31.4±6.2 ^{a}	318.0±9.1 ^{e}	17.3±0.9 ^{bc}	6.0±0 ^{ab}	160.9±8.8 ^{a}	0.86±0.1 ^{cde}	742.0±31.0 ^{c}
Lemon/lime soda + distilled water (50:50)	10.8±0.3 ^{bc}	25.8±4.4 ^{abc}	422.0±9.6 ^{c}	14.6±0.1 ^{cd}	6.0±0 ^{ab}	153.3±6.9 ^{a}	2.4±0.03 ^{a}	162.0±23.9 ^{ef}
1% sucrose + 4 mL L^{-1} vinegar	5.8±0.2 ^{g}	32.0±7.3 ^{a}	266.0±19.6 ^{fg}	14.5±0.8 ^{cd}	8.0±0 ^{a}	133.5±10.4 ^{bc}	2.08±0.3 ^{ab}	66.0±94.6^{f}
1% sucrose + 15 mL bleach	5.4±0.5 ^{g}	29.9±3.9 ^{ab}	282.0±11.11 5.2 ^{ef}	18.0±2.1 ^{abc}	7.0±0 ^{a}	166.2±5.6 ^{b}	2.34±0.5 ^{ab}	503.2±145.3 ^{cd}
Chrysal Clear Universal	12.6±0.6 ^{a}	32.2±4.0 ^{a}	568.0±15.2 ^{a}	17.5±0.9 ^{bc}	4.2±0.2 ^{b}	115.0±1.8 ^{de}	1.72±0.4 ^{abc}	1060.0±121.2 ^{b}
Floralife flower food	12.8±0.4 ^{a}	25.3±1.6 ^{abc}	506.0±25.7 ^{b}	13.1±2.1 ^{d}	1.2±0.2 ^{c}	100.7±7.0 ^{e}	0.54±0.2 ^{de}	614.0±160.2 ^{cd}
LSD value at 5%	1.1	12.0	5.9	1.2	0.2	17.3	0.24	96.9

Means with different letters in a column differ significantly from each other according to LSD test at p≤0.05.

Storage methods and durations: Cold storage of cut sunflower stems, whether under wet or dry conditions, had minimal influence on postharvest longevity at shorter durations; however, storage for 72 hours resulted in pronounced chilling injury, characterized by blackened leaves and stems, indicating a strong negative response to low-temperature exposure. Storage in water for 24 hours or 72 hours reduced vase life by 2 and 3 days, respectively, compared with unstored stems (Fig. 3). Similarly, dry storage for 24 hours or 72 hours decreased vase life by 3 and 4 days, respectively. The highest incidence of flower wilting (100%) occurred under 72-hour dry storage. Wet storage for 24 hours produced the greatest stem bending (80%). The highest stem-end rotting (100%) was recorded in stems subjected to 24-hour and 48-hour wet storage. (data not presented).

Table 7. Effect of different vase preservatives on termination symptoms of sunflower (*Helianthus annuus* L.). n = 10.

Treatments (Vase preservatives)	Stem bending (%)	Fungal attack (%)	Leaf wilt (%)	Leaf necrosis (%)	Stem end rottening (%)
Distilled water (control)	30±0.2 ^{ab}	0±0 ^{d}	0±0 ^{b}	20±0.2 ^{d}	60±0.1 ^{ab}
1% sucrose + citric acid 150 mg L^{-1}	10±0.1 ^{bc}	10±0.1 ^{cd}	40±0.2 ^{a}	10±0.1 ^{d}	10±0.1 ^{cd}
1% sucrose + 100 mg L^{-1} salicylic acid	0±0 ^{c}	60±0.2 ^{ab}	0±0 ^{b}	100.1 ^{d}	30±0.2 ^{bcd}
1% sucrose + 4 mL L^{-1} lemon juice	0±0 ^{c}	90±0.1 ^{a}	0±0 ^{b}	100±0 ^{a}	50±0.2 ^{bc}
1% sucrose + 100 mg L^{-1} aluminum sulphate	0±0 ^{c}	0±0 ^{d}	0±0 ^{b}	30±0.2 ^{cd}	10±0.1 ^{cd}
Lemon/lime soda + distilled water (50:50)	0±0 ^{c}	50±0.2 ^{abc}	40±0.2 ^{a}	60±0.2 ^{bc}	40±0.1 ^{bcd}
1% sucrose + 4 mL L^{-1} vinegar	10±0.1 ^{b}	20±0.2 ^{bcd}	30±0.2 ^{ab}	10±0.1 ^{d}	100±0 ^{a}
1% sucrose + 15 mL bleach	0±0 ^{c}	0±0 ^{d}	60±0.1 ^{a}	10±0.1 ^{d}	0±0 ^{d}
Chrysal Clear Universal	50±0.2 ^{b}	40±0.2 ^{bcd}	0±0 ^{b}	80±0.1 ^{ab}	50±0.2 ^{bc}
Floralife flower food	0±0 ^{c}	0±0 ^{d}	0±0 ^{b}	100±0 ^{a}	50±0.2 ^{bc}
LSD value at 5%	32	45	09	09	52

Means with different letters in a column differ significantly from each other according to LSD test at $p \leq 0.05$.

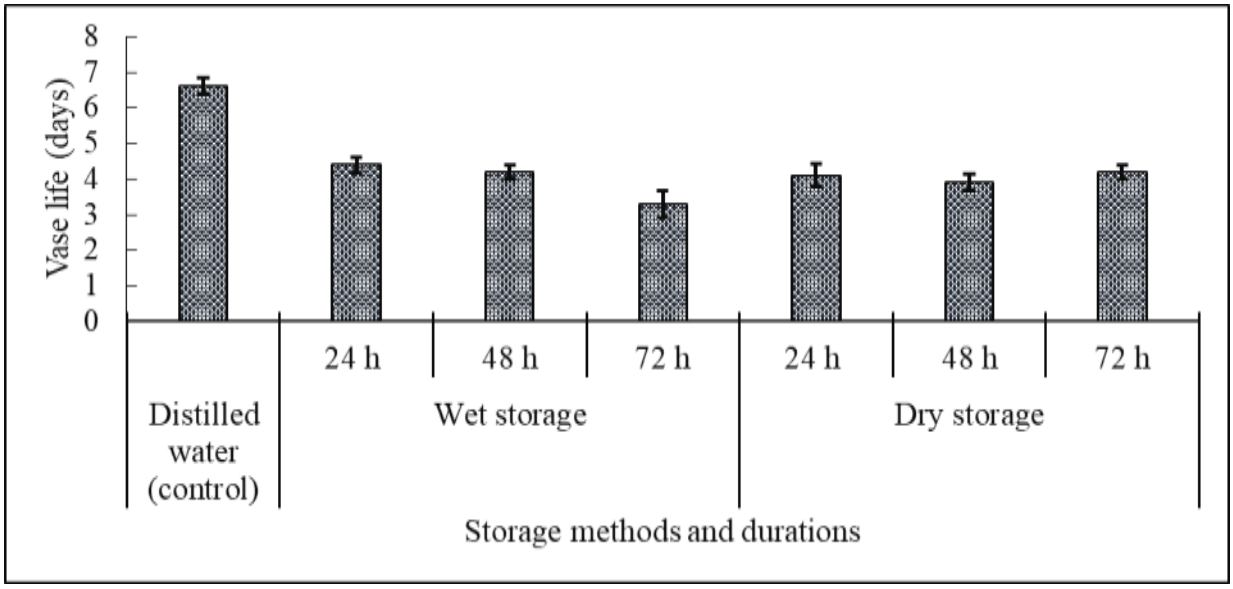

Fig. 3. Effect of storage methods and durations on vase life (days) of sunflower (*Helianthus annuus* L.). All bars represent means of 10 stems ± S.E.

DISCUSSION

The results demonstrated the importance of using the best postharvest handling practices to extend the shelf life and quality of cut sunflower stems after harvest. The appropriate stage of growth for harvest, which varies greatly between species and cultivars, has a substantial impact on sunflower quality and postharvest longevity. Stems harvested at the partially opened stage exhibited extended vase life compared to those harvested at other stages as well as more change in fresh weight. These results are in line with research by Naik *et al.* (2018), which demonstrated that cut sunflower harvesting is typically carried out at the intermediate stage, marking the ligulate flowers when 50% of the disc flowers open and the inflorescence starts to open (Curti *et al*., 2012). Stems harvested at partially opened stage demonstrated higher water uptake can be explained by the fact that flower opening necessitates high water levels since it includes high rates of cell division and expansion (Sanches *et al*., 2019).

Better water absorption and an overall healthier appearance throughout the vase life may be attributed to the cellular structures that are still in their optimum functioning phase, which is responsible for water uptake and nutrient transport. Stems harvested in evening

showed an extension of vase life by 1 day as compared to morning and noon harvested stems. Sunflower postharvest longevity is mostly dependent on harvesting time. Evening harvested stems may result in lower temperatures and more humidity, which may decrease transpiration loss and improve water absorption by cut stems.

Wet-wet stems exhibited longest vase life with more change in fresh weight and water uptake. These results suggested that wet handling was more effective than dry handling in enhancing the vase life. Dry-wet stems with an average vase life of 5 days suggest that transitioning from dry conditions to wet conditions may have some initial challenges for the stems to uptake water efficiently, but once properly hydrated, the vase life is extended. On the other hand, dry-dry stems, which experienced limited water availability throughout, had the shortest vase life, with an average of 4 days. Ensuring a continuous water supply (wet-wet) immediately after harvest significantly extended the vase life of cut sunflowers, indicating that proper hydration is crucial for their longevity. Keeping the flowers in dehydrated conditions appears to have a negative impact on vase life. On the other hand, somewhat longer vase life was observed when the flowers were maintained moist. The vase life of stems after harvest was unaffected by whether they were stored dry or wet. Longest vase life was recorded in control (stems shifted directly to the vase) as compared to stems stored for 24 h, 48, 72 h or wet and dry. Cut stems senesce early and some cut flower species cannot withstand cold storage at low temperatures due to microbial blockage (Ahmad *et al.,* 2012), or physiological disorders or diseases brought on by prolonged exposure to chilling (Dole *et al.,* 2009; Han, 2001). Pulsing of cut sunflower stems with 5% sucrose showed an increase of 2 d in vase life as compared to stems pulsed with 2% sucrose in distilled water. Use of tap water and canal water showed the decrease in vase life. These findings are consistent with Neumaier *et al.* (2008), who found decreased in vase life of Cyclamen by using tap water. Pulsing of cut sunflower stems with Chrysal Clear Universal Flower food showed the extended vase life, followed by 5% sucrose and 2% sucrose + salicylic acid 200 mg L^{-1}. Ahmad and Dole (2014) also confirmed these findings that use of Chrysal or commercial preservatives increased the vase of sunflower.

Commercial floral preservatives have been thoroughly studied and found to be an efficient way to improve vase life by providing the right amount of sugar, acidifier, and biocide. The plant-regulating and stress-reduction qualities of salicylic acid are linked to its positive benefits. Because SA is a natural, affordable, safe, and biodegradable substance, researchers strongly recommend it as a vase solution additive to prolong the postharvest life of cut flower species that are vulnerable to bacterial and ethylene-induced vascular obstruction (Tehranifar *et al*., 2013). Sugars work by controlling osmosis and the water balance of plants (Gangola and Rama Doss, 2018). Numerous studies have shown that adding 2–10% sucrose to cut flowers can effectively extend their vase life (Aydın, 2015; Ketsa and Narkbua, 2001). Commercially made lemon-lime soda, which contains sugar, acidifier, and biocide, works just as well as commercial preservatives. However, it can be utilized in situations when other treatments might be required, and commercial preservatives are not easily accessible. Use of 2% sucrose + lemon/lime juice (6 mL L^{-1}) showed detrimental effects and highest change in flower quality. The vase life was extended by treatments including only sugar and an acidifier, but not as much as by treatments with biocides. The hunt for an ecologically certified floral preservative has been ongoing for producers of organic flowers, and some have turned to lemon juice as a biocide and acidifier (Ahmad and Dole, 2014). Aluminum sulfate is bactericide commonly used in cut flower preservative solutions (Jowkar *et al*., 2013). Hajizadeh *et al.* (2012) demonstrated that in *Rosa hybrid* cv. Black Magic, aluminum sulfate treatments were the most significant factor in increasing longevity and water uptake. Additionally, aluminum sulfate's antibacterial properties increased cut rose flower postharvest quality, water relations and vase life (Rezvanypour and Osfoori, 2011).

Highest change in EC was recorded in 2% sucrose + GA (100 mg L^{-1}) + BA (100 mg L^{-1}) + CA (100 mg L^{-1}) and highest pH in 2% sucrose + salicylic acid 200 mg L^{-1}. Electrolyte leakage is caused by the degradation of membrane lipids as leaf senescence increased. Electrolyte leakage has been regarded as a measure of plant senescence-related membrane degradation and integrity (Maalekuu *et al*., 2006). Petals electrolyte leakage percentage has been increasing with the increase in aging of flowers. Treatments having more vase life directly affect the electrolyte leakage percentage. Stems constantly immersed in commercial floral preservatives showed the longest vase life, the greatest change in fresh weight, and the highest water uptake. The vase life of many cut flower species is greatly shortened by the growth of microorganisms in vase solutions. The vase life is extended by adding germicides (fungicide and bactericide) to the vase solution that are believed to have a lowering effect on microbial growth. Bacterial development in vase water has been shown to obstruct cut roses' transmission bundles and influence water intake reduction (Aydın, 2015). Ahmad and Dole (2014) reported increase in vase life using commercial preservatives (Floralife and Chrysal) in cut sunflower. These results are aligned with our results. Kiamohammadi (2011) examined the effects of antimicrobial agents on the vase life of *Eustoma grandiflorum* and discovered that, when compared to the control, 160 mg L^{-1} of aluminum sulfate resulted in the

greatest extension of vase life. Furthermore, according to Farhat *et al*. (2014), sucrose and aluminum sulfate work better together to extend the vase life of roses.

Conclusion: Sunflower harvested at partially opened stage preferably in evening and placed immediately in buckets with water performed best and had longest vase life. Handling of stems in distilled water for a day along with 5% overnight sucrose pulsing was acceptable for nearby markets. Handling stems in commercial floral preservative or 2% sucrose + 100 mg L^{-1} aluminum sulphate, or distilled water + lemon/lime soda (50:50) until termination proved best preservatives for longest vase life and may be used by florists while postharvest handling of cut sunflower stems.

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