






SCIENTIFIC ARTICLE

Preservative solutions on vase life and quality of cut *Polianthes tuberosa* L.

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ABSTRACT

This experiment was conducted to study the effectiveness of different preservative solutions on vase life and quality of angelica cut inflorescences cv. Single. The concentrations of citric acid at 100, 200 and 300 mg L⁻¹, sucrose at 3% and 4% and H₂O₂ at 0.1%, 0.2% and 0.3% were used as preservatives, while distilled water was used as control. The single factor experiment was laid out in a completely randomized design (CRD) with three replications. Citric acid and H₂O₂ solutions effectively inhibited bacterial growth-related blockage in the vascular tissues, but had adverse effects on the vase life. The inflorescences stored in sucrose (3% and 4%) solutions remained fresh up to 10 days after preservation (DAP), maintaining good solution uptake, controlling transpiration loss and gaining higher relative fresh weight. Different quality parameters like floret diameter and number of opened florets were also significantly higher in inflorescences preserved in sucrose (3% and 4%) solution, followed by control, citric acid and H₂O₂, respectively, in different DAP. Overall, the inflorescence of cut tuberose preserved in sucrose, particularly at 4% solutions, showed better postharvest quality than other preservatives and maximum vase life.

Keywords: tuberose; sucrose; citric acid; hydrogen peroxide.

RESUMO

Soluções conservantes na vida de vaso e qualidade de *Polianthes tuberosa* L. de corte

Este experimento foi conduzido para estudar a eficácia de diferentes soluções conservantes na vida de vaso e na qualidade de inflorescências de angélica de corte cv. Single. As concentrações de ácido cítrico a 100, 200 e 300 mg L⁻¹, sacarose a 3% e 4% e H₂O₂ a 0,1%, 0,2% e 0,3% foram utilizadas como conservantes, enquanto a água destilada foi utilizada como controle. O experimento de fator único foi desenvolvido em um delineamento completamente randomizado (CRD), com três repetições. As soluções de ácido cítrico e H₂O₂ inibiram efetivamente o bloqueio relacionado ao crescimento bacteriano nos tecidos vasculares, mas tiveram efeitos adversos na vida de vaso. As inflorescências armazenadas em soluções de sacarose (3% e 4%) permaneceram frescas até 10 dias após a preservação (DAP), mantendo boa absorção da solução, controlando a perda de transpiração e ganhando maior massa fresca relativa. Diferentes parâmetros de qualidade, como o diâmetro do florete e o número de floretes abertos também foram significativamente superiores para as inflorescências preservadas em solução de sacarose (3% e 4%), seguida pelo controle, ácido cítrico e H₂O₂, respectivamente, em diferentes DAP. De maneira geral, as inflorescências de angélicas mantidas em sacarose, particularmente em soluções a 4%, apresentaram melhor qualidade pós-colheita e maior vida de vaso em relação aos outros conservantes.

Palavras-chave: angélica; sacarose; ácido cítrico; peróxido de hidrogênio.

INTRODUCTION

Tuberose (*Polianthes tuberosa* L.) is a member of Agavaceae and its inflorescence (spike) bears 10–20 pairs of florets that open acropetally. It has long been cherished for the aromatic oils extracted from its fragrant white inflorescence, and has recently gained popularity as a cut flower. The fragrance of tuberose comprises a blend

of different volatile compounds (Babarabie et al., 2017), which have antimicrobial and antifungal properties and provide some health benefits against insomnia, influenza, and rheumatism (Rani and Singh, 2013). Tuberose are mainly cultivated for the commercial production of their cut flowers, which constitutes a considerable portion of the floriculture business in Bangladesh. However, the vase life of cut tuberose are usually short, and that reduces its quality

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and commercial value during transportation, marketing and even at the customer level. Tuberose is sensitive to ethylene production, which results in the wilting and burning of florets and bending of the tips of flower spikes, as well as reduced vase life (Pérez-Arias et al., 2019).

In the floral industry, different preservative solutions are used to increase the vase life of cut flowers and keep them fresh for longer periods. Among these solutions, sucrose, which acts as a food source or respiratory substrate, delays the degradation of proteins and maintains the turgidity of expanding flower petals, is widely used (Rabiza-Świder et al., 2020). Several reports have shown that antibacterial compounds, like citric acid, are beneficial for decreasing pH of vase solutions, as well as the rate of bacterial growth, which is supposedly due to the reduction in vascular blockage (Van Doorn, 2012). In addition, a low concentration of hydrogen peroxide (H_2O_2) could be used as a biocontrol agent to counter several abiotic and oxidative stresses during the postharvest time of fresh commodities (Herrera-Vásquez et al., 2015). It is necessary to compare the effectiveness of these preservative solutions in lengthening the vase life of cut tuberose. Therefore, in the present research, the efficacy of sucrose, citric acid and hydrogen peroxide in extending the vase life of cut tuberose cv. Single was evaluated.

MATERIAL AND METHODS

Plant material

The present work was undertaken in the laboratory of Horticulture, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh. The fresh-cut flowers of tuberose cv. Single came from the garden of Horticulture Centre, Department of Agricultural Extension, Dinajpur, Bangladesh. The flowers were harvested between 7:00 a.m. and 8:00 a.m., when two or three basal florets were open. The flowers were placed in cool water just after harvesting and transported to the laboratory. Afterwards, a 60 cm long stem was trimmed, and a smooth slanting cut was given to each cut stem, in order to facilitate the optimum uptake of the preservative solutions. The cut flowers were placed 7 cm under 300 mL preservative solution, in a 500 mL Erlenmeyer flask, and kept in ambient condition (temperature: $25 \pm 5^\circ C$ and relative humidity: $60 \pm 5\%$). The cut flowers were monitored throughout 2, 4, 6, 7, 8, 9 and 10 days after preservation (DAP).

Treatments and experimental design

The single factor experiment comprised of 8 treatments: distilled water (DW as control), 3 levels of citric acid (100, 200 and 300 mg L^{-1} citric acid solution), 2 levels of sucrose (3% and 4% sucrose solution) and 3 levels of H_2O_2 (0.1%, 0.2% and 0.3% H_2O_2 solution). The experiment was arranged in a completely randomized design (CRD), with three replications.

Preparation of preservative solutions

The citric acid (Merck, India) was weighed at 100, 200 and 300 mg, and each was dissolved into 1 L DW.

For 3% and 4% sucrose solution, 30 and 40 g of sucrose (Qualikems, India) were weighed, and each was put into 1 L of DW. The 30% H_2O_2 (Merck, India) was pipetted at 3.33, 6.67 and 10 mL, and each was diluted into 1 L DW. All the solutions were made just before the experimental setup.

Solution uptake and transpiration loss

Solution uptake was measured by the difference between consecutive weights of conical flask plus solution, and represented in mL (Ahmad et al., 2018), whereas transpiration loss of water of cut flower was recorded from the difference between consecutive weights of conical flask plus solution plus tuberose inflorescence, and expressed in mL.

Transpiration loss (mL)

$$= \text{Current weight of (conical flask + solution + tuberose inflorescence)} \\ - \text{Previous weight of (conical flask + solution + tuberose inflorescence)}$$

Number and diameter of florets

The number of opened florets and unopened floral buds per inflorescence was counted at DAP. Floret diameter was defined as the maximum diameter of each floret. It was measured from apex of two opposite florets by an electrical digital slide calliper (Guanglu, China), using the procedure of Wei et al. (2021).

Changes of relative fresh weight

The difference between the weight of Erlenmeyer flask with vase solutions (with flower) and the weight of Erlenmeyer flask with vase solution (without flower) were recorded at every alternate day interval to measure the fresh weight change of the flower during that particular time period. Changes of relative fresh weight were obtained by subtracting 100 from relative fresh weight (He et al., 2006), where W_t = the weight of stem (g) at $t=2, 4, 6, 7, 8, 9, 10$ DAP and $W_{t=0}$ is the weight of the same stem (g) at initial day (Equation 1).

$$\text{Changes of RFW} = \left(\frac{W_t}{W_{t=0}} \times 100 \right) - 100 \quad (1)$$

Changes of pH and solution turbidity

Solution turbidity attributable to microbial growth was assessed at 1, 4, 6, 7, and 10 DAP by measuring absorbance at 500 nm with a spectrophotometer (BK-UV1800 Vis Spectrophotometer, China), calculating the difference from the absorbance of respective preservation solution (Knee, 2000). Solution pH was determined using a pH meter (Hanna Instruments Model HI2211, Michigan, USA).

Vase life and anatomical sectioning of inflorescence

The vase life was determined as the number of days and it was considered as the period between harvest and

the time when more than 50% of florets were wilted (Wei et al., 2021). Wilting symptoms were observed in the inflorescences of tuberoses after 6 DAP in H_2O_2 solutions and control and citric acid solutions after 7 DAP, and, for this reason, the results for these treatments are not presented in the tables. The anatomical sectioning of tuberose inflorescence was made and observed under a compound microscope (Uniteck Scientific & Electronic Industry, India) with (10 \times) magnification power by following the protocol of Park et al. (2017). The data was measured by observation on a scale of 15, where 1 \leq 15%, 2=16%–30%, 3=31%–45%, 4=46%–60% and 5>60% represent vascular blockage in the tuberose inflorescence xylem.

Statistical analyses

Statistical analysis of variance (ANOVA) was performed using the RStudio version 1.2.1335 statistical software (RStudio Team, 2019). The means were compared using Fisher's Least Significant Difference (LSD) test.

RESULTS AND DISCUSSION

Solution uptake

Solution uptake was significantly ($P<0.05$) influenced by different treatments at different DAP (Table 1). At the beginning of storage (2 and 4 DAP), the flower sticks absorbed a comparatively higher amount of solution regardless of storage treatments. Means comparison indicated that aqueous solutions of sucrose (3% and 4% sucrose) had a more positive effect on increasing solution uptake than other preservative solutions. Initially, citric acid and H_2O_2 solutions performed better, but, after 4 DAP, the inflorescences preserved in these solutions were unmarketable due to high wilting symptoms. The preservative solutions containing 3% and 4% sucrose showed higher uptake of vase solution, because sucrose helps to maintain water balance and delays turgor loss. Kumar and Deen (2017) state that a high concentration of sucrose solutions enhanced higher solution uptake in tuberose cv. Hyderabad Double.

Table 1. Solution uptake of tuberose at different days after preservation.

Treatment	Solution uptake (mL)						
	2 DAP	4 DAP	6 DAP	7 DAP	8 DAP	9 DAP	10 DAP
DW	30.33 e	32.33 b	11.33 d	4.77 d	-	-	-
100 mg L ⁻¹ CA	31.33 de	33.67 b	14.69 c	5.33 d	-	-	-
200 mg L ⁻¹ CA	33.71 bcd	41.33 a	16.12 bc	6.68 c	-	-	-
300 mg L ⁻¹ CA	35.67 abc	42.11 a	16.33 bc	8.47 b	-	-	-
3% Sucrose	36.33 ab	43.15 a	18.12 b	9.66 a	5.07 b	3.85 b	2.68 a
4% Sucrose	37.27 a	44.33 a	21.33 a	9.90 a	6.10 a	4.91 a	3.07 a
0.1% H_2O_2	33.67 bcd	41.23 a	15.67 bc	5.67 cd	-	-	-
0.2% H_2O_2	34.95 abc	39.67 a	14.33 c	-	-	-	-
0.3% H_2O_2	32.67 cde	33.12 b	11.67 d	-	-	-	-
LSD (0.05)	3.30	5.15	2.57	1.05	0.68	0.68	0.45
CV (%)	5.66	7.69	9.67	8.32	5.37	6.85	6.96

DW: distilled water; CA: citric acid; LSD: least significant difference; CV: coefficient of variation; DAP: days after preservation.

Transpiration loss

Transpiration loss was increased during the experiment, however, the rate of transpiration loss was higher at 4 DAP, irrespective of storage treatments, and, afterwards, the rate declined over the storage period. Higher transpiration loss was recorded in control, citric acid (100 and 200 mg L⁻¹) and H_2O_2 solutions at different DAP (Table 2). As a whole, sucrose solutions were found to be the best preservative solution in respect to transpiration loss, and, at the end of storage, lower transpiration loss was recorded at 4%

(6.33 mL) compared to 3% (8.20 mL) sucrose solution. From the present experiment, it is evident that sucrose solution is effective in controlling transpiration loss of cut tuberoses. Earlier, Aryal et al. (2019) observed that sucrose solution increased the vase life of roses by reducing transpiration loss and influencing water uptake. The high transpiration loss in the H_2O_2 solution might be due to higher chemical stress and/or shortage of carbohydrates in the solutions, resulting in quicker wilting in this treatment when compared to others.

Table 2. Transpiration loss of tuberose at different days after preservation.

Treatment	Transpiration loss (mL)						
	2 DAP	4 DAP	6 DAP	7 DAP	8 DAP	9 DAP	10 DAP
DW	20.33 a	44.67 a	39.00 a	36.67 a	-	-	-
100 mg L ⁻¹ CA	19.67 ab	42.67 ab	38.33 a	36.33 a	-	-	-
200 mg L ⁻¹ CA	17.33 bc	39.00 bc	36.33 abc	35.33 ab	-	-	-
300 mg L ⁻¹ CA	17.36 bc	38.00 c	34.67 bc	32.33 b	-	-	-
3% Sucrose	17.00 c	37.00 c	34.67 c	32.33 b	26.67 a	11.67 a	8.20 a
4% Sucrose	16.67 c	36.67 c	34.33 c	31.67 b	23.70 a	10.33 a	6.33 b
0.1% H ₂ O ₂	18.33 abc	39.67 bc	37.38 abc	34.67 ab	-	-	-
0.2% H ₂ O ₂	18.67 abc	41.00 abc	37.58 ab	-	-	-	-
0.3% H ₂ O ₂	20.33 a	41.00 abc	37.67 ab	-	-	-	-
LSD	2.48	4.63	3.13	3.15	3.52	1.59	1.30
CV (%)	7.85	6.76	4.98	6.23	6.16	6.36	7.87

DW: distilled water; CA: citric acid; LSD: least significant difference; CV: coefficient of variation; DAP: days after preservation.

Diameter of floret

The size of floret has always been one of the most important morphological indicators of cut tuberose. In general, the diameter of the floret was increased, and, afterwards, decreased on the progress of the storage period. Initially, the highest diameter of floret was measured in citric acid and sucrose treatments. At the end of storage, flowers preserved in sucrose solutions had the highest diameter of floret compared to other treatments (Table 3). Initially, citric

acid maintained a higher diameter of floret, which could be due to the fact that this chemical reduced bacterial growth and prevented vascular blockages, but, later on, could not supply respiratory substrates for the opening florets. Similar results had been recorded by Kumari et al. (2018) in cut tuberose cv. Calcutta Single. Overall sucrose (3% and 4%) solution performed better to maintain the diameter of floret, as this solution provided adequate food sources or carbohydrates, resulting in higher floral diameter.

Table 3. Floret diameter of a particular tuberose floret at different days after preservation.

Treatment	Floret diameter (mm)						
	2 DAP	4 DAP	6 DAP	7 DAP	8 DAP	9 DAP	10 DAP
DW	16.79 bc	32.21 ab	22.89 def	16.58 d	-	-	-
100 mg L ⁻¹ CA	19.94 a	33.11 a	23.77 de	17.71 cd	-	-	-
200 mg L ⁻¹ CA	18.98 a	33.55 a	24.49 d	19.87 c	-	-	-
300 mg L ⁻¹ CA	18.37 ab	34.34 a	28.58 c	25.85 b	-	-	-
3% Sucrose	18.50 ab	28.21 bc	35.46 b	32.86 a	28.40 a	25.23 a	22.37 a
4% Sucrose	18.57 a	28.20 bc	38.43 a	35.60 a	31.61 a	28.48 a	25.35 a
0.1% H ₂ O ₂	15.41 c	33.31 a	21.13 ef	15.18 d	-	-	-
0.2% H ₂ O ₂	15.37 c	31.79 ab	20.21 f	-	-	-	-
0.3% H ₂ O ₂	12.65 d	27.41 c	15.48 g	-	-	-	-
LSD	1.72	4.12	2.90	3.29	4.53	5.78	5.13
CV (%)	5.82	7.66	6.60	8.05	6.67	9.49	9.49

DW: distilled water; CA: citric acid; LSD: least significant difference; CV: coefficient of variation; DAP: days after preservation.

Number of opened and unopened florets per inflorescence

The number of opened florets increased significantly from 2 DAP, and reached a maximum number of opened florets at 4 DAP, regardless of preservative solution.

Afterwards, the number of opened florets decreased with the advancement of vase life; however, the decreasing rate was comparatively slower in sucrose solutions (Table 4). On the contrary, the highest number of unopened florets was counted in control and H₂O₂ solutions compared to

other storage treatments. In this study, sucrose solutions promoted the opening of the floret of the tuberoses because flower buds require carbohydrates to open, and, without sucrose, florets failed to open naturally. Sucrose provides essential substrate for respiration, structural material and carbon skeletons for bud opening (Rabiza-Świder et al., 2020). The maximum number of unopened flower buds per inflorescence in other treatments may be due to the

fact that adequate moisture alone could not assist to open florets. Overall sucrose (3% and 4%) solution performed better to maintain the diameter of florets, as this solution provided adequate food sources or carbohydrates, resulting in higher floral diameter. Similar improvement was reported by Kumari et al. (2018) in the opening of florets with high sucrose concentration in cut tuberose cv. Calcutta Single.

Table 4. Number of opened florets at different days after preservation and unopened buds of tuberose at the end of vase life.

Treatment	Number of opened florets							Unopened buds
	2 DAP	4 DAP	6 DAP	7DAP	8 DAP	9 DAP	10 DAP	
DW	1.23 d	4.83 b	1.33 f	1.22 d	-	-	-	27.29 a
100 mg L ⁻¹ CA	1.20 d	5.63 a	1.33 f	1.23 d	-	-	-	25.47 ab
200 mg L ⁻¹ CA	1.34 c	5.94 a	1.43 f	1.43 cd	-	-	-	21.67 c
300 mg L ⁻¹ CA	1.47 bc	5.93 a	2.67 c	1.56 c	-	-	-	22.33 bc
3% Sucrose	1.85 a	5.42 a	3.17 b	2.00 b	2.10 b	1.87 b	1.36 a	14.67 d
4% Sucrose	1.57 b	5.49 a	3.79 a	2.67 a	2.67 a	2.23 a	1.45 a	16.00 d
0.1% H ₂ O ₂	1.32 c	4.59 b	3.24 b	1.59 c	-	-	-	25.34 ab
0.2% H ₂ O ₂	1.23 d	4.35 b	2.23d	-	-	-	-	26.67 a
0.3% H ₂ O ₂	1.21 d	4.26 b	1.89 e	-	-	-	-	27.67 a
LSD	0.19	0.58	0.31	0.28	0.45	0.45	0.17	3.43
CV (%)	8.04	6.60	7.69	9.57	8.39	9.77	5.33	8.69

DW: distilled water; CA: citric acid; LSD: least significant difference; CV: coefficient of variation; DAP: days after preservation.

Changes of relative fresh weight

In general, the inflorescence of tuberose gained relative fresh weight up to 4 DAP; afterwards, the inflorescence lost their fresh weight with the progress of vase life, regardless of storage treatments. Despite relatively low losses of fresh weight from 6 to 10 DAP, sucrose-containing solutions had the highest fresh weight compared to other treatments, and, particularly, 4% sucrose solution was the most effective

treatment (Table 5). The present result showed that the highest fresh weight was obtained by sucrose solution, as it provided carbohydrates, enhanced solution uptake and controlled transpiration losses of the tuberose inflorescences. A recent study with cut roses by Kshirsagar et al. (2021) noted similar results: 2% sucrose solution increased the fresh weight of the flower as it enhanced the quality of rose by reducing the respiration and transpiration rate.

Table 5. Changes of relative fresh weight (%) of tuberose inflorescence at different days after preservation.

Treatment	Changes of relative fresh weight (%)						
	2 DAP	4 DAP	6 DAP	7 DAP	8 DAP	9 DAP	10 DAP
DW	4.66 d	3.06 d	-12.20 g	-26.44 e	-	-	-
100 mg L ⁻¹ CA	5.77 c	3.86 c	-10.51 fg	-24.78 de	-	-	-
200 mg L ⁻¹ CA	6.07 bc	6.37 b	-6.24 c	-21.00 cd	-	-	-
300 mg L ⁻¹ CA	6.11 bc	6.83 b	-5.93 c	-19.49 ab	-	-	-
3% Sucrose	6.90 ab	7.86 a	-5.23 b	-19.55 bc	-31.63 a	-37.78 b	-42.16 b
4% Sucrose	7.06 a	8.06 a	-4.94 a	-17.39 a	-27.51 a	-32.88 a	-34.70 a
0.1% H ₂ O ₂	5.83 c	3.82 c	-7.03d	-23.28 de	-	-	-
0.2% H ₂ O ₂	5.55 c	3.63 cd	-8.42 de	-	-	-	-
0.3% H ₂ O ₂	5.50 cd	3.31 cd	-9.06 ef	-	-	-	-
LSD	0.86	0.74	0.94	2.54	4.76	5.67	9.07
CV (%)	8.42	8.33	7.12	6.67	7.10	7.07	10.41

DW: distilled water; CA: citric acid; LSD: least significant difference; CV: coefficient of variation; DAP: days after preservation.

Changes in solution turbidity

In general, the value of solution turbidity was initially low, and, afterwards, increased gradually with the preservation period. Minimum changes in solution turbidity (absorbance) were recorded both in the citric acid and H₂O₂ solutions, whereas both sucrose and control solutions had relatively higher changes of turbidity at different DAP (Table 6). The higher absorbance value of sucrose and control solutions indicated a higher number of pathogens in these solutions.

Although sucrose solution enhances bacterial multiplication in the preservative solution, it also supplies carbohydrates to cut flowers and increases its vase life (Gebremedhin et al., 2013). On the contrary, citric acid and H₂O₂ solutions had minimum changes in absorbance in all cases, indicating this solution limits bacterial growth by lowering the pH level of the solutions. Van Doorn (2012) and Liao et al. (2012) reported that citric acid acted as a pH regulator that reduced bacterial proliferation in the preservative solutions.

Table 6. Changes in solution turbidity of preservative solutions at different days after preservation.

Treatment	Changes in solution turbidity (absorbance)			
	4 DAP	6 DAP	7 DAP	10 DAP
DW	0.018 b	0.022 c	0.029 b	-
100 mg L ⁻¹ CA	0.012 b	0.020 c	0.026 b	-
200 mg L ⁻¹ CA	0.010 cd	0.013 d	0.017 cd	-
300 mg L ⁻¹ CA	0.008 de	0.008 e	0.015 d	-
3% Sucrose	0.019 b	0.025 b	0.030 b	0.035 b
4% Sucrose	0.022 a	0.030 a	0.036 a	0.041 a
0.1% H ₂ O ₂	0.007 ef	0.014 d	0.020 c	-
0.2% H ₂ O ₂	0.007 ef	0.009 e	-	-
0.3% H ₂ O ₂	0.005 f	0.007 e	-	-
LSD	0.003	0.003	0.005	0.006
CV (%)	13.608	9.289	10.596	6.709

DW: distilled water; CA: citric acid; LSD: least significant difference; CV: coefficient of variation; DAP: days after preservation.

Changes in pH

Freshly prepared citric acid solutions (100, 200 and 300 mg L⁻¹) had comparatively lower pH than other preservative solutions, as they released more H⁺ in the solution (Table 7). The freshly prepared sucrose and H₂O₂ containing solutions had pH near neutral. However, minimum changes in pH were detected in different DAP, and pH

value was increased over the storage period, irrespective of treatments. The increasing trend of pH during vase life might be associated with the higher multiplication of microorganisms in the solution, transport physiology and metabolism of cut flower; similar results were also noted by Shanani (2017) in *Rosa hybrida* cv Teresa.

Table 7. pH of preservative solution at different days after preservation.

Treatment	pH				
	Initial	5 DAP	6 DAP	7 DAP	10 DAP
DW	7.16 a	6.89 a	7.24 a	7.28 a	-
100 mg L ⁻¹ CA	5.72 b	5.81 b	5.88 b	5.92 b	-
200 mg L ⁻¹ CA	4.70 c	4.79 c	4.81 c	4.83 c	-
300 mg L ⁻¹ CA	4.24 c	4.19 c	4.23 c	4.25 c	-
3% Sucrose	7.17 a	7.23 a	7.28 a	7.32 a	7.42 a
4% Sucrose	7.16 a	6.93 a	7.29 a	7.34 a	7.43 a
0.1% H ₂ O ₂	7.16 a	7.21 a	7.22 a	7.25 a	-
0.2% H ₂ O ₂	6.89 a	7.18 a	7.21 a	-	-
0.3% H ₂ O ₂	6.89 a	7.17 a	7.18 a	-	-
LSD	0.61	0.79	0.94	0.70	0.79
CV (%)	5.56	7.24	8.48	6.34	8.78

DW: distilled water; CA: citric acid; LSD: least significant difference; CV: coefficient of variation; DAP: days after preservation.

Vase life

Different preservative solutions had a significant effect ($P<0.05$) on the vase life of tuberose. Vase life of cut tuberoses was extended by 3% and 4% sucrose solution up to 10 days when compared to control and citric acid solutions (7 days), while H_2O_2 solution (0.2% and 0.3%) shortened the vase life to 6 days only (Table 8). H_2O_2 treatments at all concentrations caused low water uptake, high transpiration loss and accelerated floret abscission. Increasing concentration of sucrose markedly delayed senescence and increased the vase life of cut tuberoses, which might be due to the supply of respiratory substrate for the maintenance of osmotic potential. Singh et al. (2018) also reported that 4% sucrose solution increased the vase life of tuberose significantly, as the peroxidase activity was the lowest. However, there were no significant differences in vase life between citric acid and control treatments.

Table 8. Effect of different preservative solutions on vase life of tuberose.

Treatment	Vase life (days)	Blockage level*
DW	7.13 bcd	3.33 bc
100 mg L ⁻¹ CA	7.22 bc	3.33 bc
200 mg L ⁻¹ CA	7.38 b	2.33 d
300 mg L ⁻¹ CA	7.44 b	2.33 d
3% Sucrose	10.20 a	3.67 ab
4% Sucrose	10.34 a	4.33 a
0.1% H_2O_2	7.22 bc	2.67 cd
0.2% H_2O_2	6.22 cd	2.33 d
0.3% H_2O_2	6.11 d	2.00 d
LSD	1.03	0.93
CV (%)	7.80	18.60

*Based on a scale of 1-5, where 1%≤15%, 2=16%-30%, 3=31%-45%, 4=46%-60%, 5>60% represent vascular blockage; DW: distilled water; CA: citric acid; LSD: least significant difference; CV: coefficient of variation.

Anatomical sectioning of inflorescence

After transverse sectioning of inflorescence, the data on blockage in xylem was 4.33 and 3.67, observed in the section of inflorescence which was kept in 3% and 4% sucrose solution respectively, which might be due to the deposition of sugars or/and microbial growth in the xylem (Table 8). A recent study on carnation cv. Edun also found that sucrose promoted the growth of blockage in xylem vessels, as sucrose encourages bacterial growth both in the vase solution and in the vascular tissue, which impeded water uptake by flower stems and caused wilting or senescence (Park et al., 2017). Despite xylem blockage, sucrose solution provided essential carbohydrates to the inflorescence of tuberose, which, ultimately, enhanced the vase life of the cut flower. On the contrary, inflorescence in citric acid and H_2O_2 solution showed less xylem blockage, as it prevented

microbial growth in the xylem. Van Doorn (2012) reported similar results: citric acid reduced bacterial proliferation and enhanced water conductance in xylem of cut flowers.

CONCLUSIONS

Vase life and quality of cut tuberoses were associated with their efficient ability of water uptake and control of transpiration loss, as well as their capacity to protect themselves against pathogens. Although citric acid and H_2O_2 solutions showed a great effect on inhibition of bacterial growth-related blockage in the vascular tissues of inflorescence, limited food sources or respiratory substrates decreased the vase life and quality of cut tuberoses. In conclusion, sucrose, particularly at 4% solution, effectively improved the quality parameters in most of the cases, which, ultimately, increased the vase life and quality of cut tuberose cv. Single.

AUTHOR CONTRIBUTION

This work was carried out in collaboration among all authors. Authors **DP** and **SM** designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Authors **AJ**, **AAM** and **JA** edited the manuscript. All authors read and approved the final manuscript.

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