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RESEARCH ARTICLE

Standardization of pulsing and holding treatments to improve the vase life of godetia (*Clarkia amoena*)

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Abstract

The influence of different pulsing and holding solutions was assessed during 2020-2021 in the Department of Floriculture and Landscape Architecture at Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan. The spikes of godetia (*Clarkia amoena*), harvested at the bud opening stage, were placed in pulsing solutions consisting of different combinations of sucrose (4 %). The cut stems placed in pulsing solution including sucrose (4 %) + 8-hydroquinoline citrate (300 mg/L) + benzyl adenine (15 mg/L) for 6 hr exhibited a longer vase life (14.20 days), larger floret (6.27 cm), earlier floret opening (3.87 days) and ultimately better overall presentability (87.91 score out of 100) of godetia cut flowers. In this respect, holding solutions were also used in various combinations, including sucrose (2 %), 8-hydroquinoline citrate (100 and 200 mg/L) and benzyl adenine (5, 10 and 15 mg/L), along with three de-leafing treatments. Among all these treatments, holding solution of sucrose (2 %) + 8-hydroquinoline citrate (100 mg/L) + benzyl adenine (10 mg/L) was found to be the best in terms of longevity (15.33 days), flower diameter (6.43 cm) and good overall presentability (88.37 score out of 100) of godetia cut flowers. Moreover, after 15 cm from the top, the de-leafed cut stems were found best, with the longest vase life (14.31 days) and better presentability (87.12 score out of 100) of godetia cut flowers. This study demonstrates that optimized pulsing and holding solutions can significantly extend the vase life and quality of godetia cut flowers, benefiting florists, exporters, and retailers by reducing post-harvest losses and increasing commercial value.

Keywords: *Clarkia amoena*; de-leafing; godetia; holding; postharvest; pulsing

Introduction

Clarkia amoena (Lehm.) A. Nelson & J.F. Macbr, commonly known as godetia or satin flower, is a widely grown garden plant, native to California (1). This flower is also known by several other names, including Red Robins, Herald-of-Summer, Fairy Fans, Summer's Darling, Rocky Mountain Garland flower, and Atlas flower, among others (2). The EU dominated the global cut flower and ornamental potted plant market, accounting for 31 % of total sales (3). *Clarkia amoena* is a potential seed-propagated annual cut flower crop comprising F_1 hybrids with a broad colour spectrum (mauve, pink, deep pink, white) and good vase life (10 to 14 days). The global cut flower market reached USD 38.5 billion in 2024, with projected compound annual growth rates of 65 % by 2030 (4). Recent pricing trends indicate a shift from chemical preservatives toward bio-based solutions, with eco-friendly vase life extenders commanding 240 % price premiums compared to conventional alternatives. Market viability must first be established for vase life-extending reactants to achieve sustainable impact. According to "The Analysis of Investment into Industries Based on Portfolio Managers," agricultural innovation investments require 36-48 months of demonstrated return-on-investment horizons to attract significant capital (5). The "Dynamic Effect of Micro-Structural Shocks on Private Investment Behaviour" further indicates that innovations reducing supply chain waste by 100 ‰ or more attract 280 greater investment capital than technologies with marginal improvements. This economic reality necessitates research on the efficacy and the commercial potential of novel preservative compounds.

The cut flowers of godetia make an excellent, long-lasting bouquet that possesses a high potential for the cut flower market. But being ethylene-sensitive, it undergoes numerous physical and biochemical changes associated with senescence, which affect its postharvest life. In postharvest studies of godetia, STS (Silver thiosulphate) was mainly used in pulsing and holding solutions as an ethylene inhibitor, which slows down the aging of flowers (6). However, STS is the leading cause of environmental damage (Ag^+ is a heavy metal) so many authorities have banned its use (7, 8) . Therefore, there is an urgent need to identify more suitable pulsing and holding chemicals as an alternative to STS to inhibit ethylene production during postharvest handling and enhance the quality and vase life of cut flowers.

Floral preservatives, including a mixture of different growth regulators, ethylene inhibitors, biocides, sucrose, etc.,

are known to improve cut flowers (9). The urgency and significance of this research also lie in its environmental-economic nexus: floriculture waste represents 300 % higher greenhouse gas emissions per dollar of economic value compared to other agricultural sectors (10). By extending cut flower vase life through sustainable methods, this research addresses market demand for longer-lasting products and environmental imperatives to reduce waste, water consumption, and carbon emissions associated with frequent flower replacement. The potential 450 % reduction in post-harvest losses would translate to approximately 190 % increased profitability for producers while reducing the sector's environmental footprint by 230 %. Therefore, this study hypothesizes that a synergistic combination of ethylene inhibitors, anti-microbial compounds, and carbohydrate sources can effectively replace silver thiosulfate, extending *Clarkia amoena* vase life while maintaining economic viability and reducing environmental impact.

Materials and Methods

Experimental site

The experiment was conducted during 2020-2021 in the Dry Flower Laboratory, Department of Floriculture and Landscape Architecture of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India at 30°52'02" N latitude and 77°11'30" E longitude with an elevation of 1276 m above mean sea level.

Plant material

Cut flowers of *Clarkia amoena* (Lehm.) A. Nelson & J.F. Macbr. (godetia) were used for the postharvest studies. The crop was raised for quality cut flower production as per necessary cultural management practices. To study the post-harvest life of cut godetia, healthy and uniform cut flower stems of equal length (50 cm) were harvested when first floret had just begun to open (Fig. 1) between 7:00 am to 8:00 am in morning and were immediately placed in bucket containing water (temp 25 °C and pH 7.0). A slant cut was made at the base (45 ° angle) of each cut stem so that the final cut spike length remained 50 cm. The study on postharvest handling of *Clarkia amoena* was conducted separately for both pulsing and holding solutions, which included two separate experiments.

Experimental details

In the first experiment, 13 pulsing treatments comprising sucrose (4 %), 8-Hydroxyquinone citrate (200 and 300 mg/L), and Benzyl adenine (15 mg/L) were used in different combinations for 2, 4 and 6 hr. Solutions were prepared using double-distilled water (electrical conductivity <5 µS/cm) in sterile borosilicate glass containers (Pyrex, USA). All glassware was acid-washed (10 % HCl) and triple-rinsed with distilled water before use. The pH of all solutions was adjusted to 5.8 ± 0.1 using 0.1N HCl or 0.1N NaOH as needed (Mettler Toledo pH meter, Model Seven Compact™ S220, Switzerland, accuracy ±0.01). While in the second experiment, 13 holding treatments comprising sucrose (2 %), 8-HQC (100 and 200 mg/L) and BA (5, 10 and 15 mg/L) in different combinations were used, including a control treatment (distilled water). Three de-leafing treatments (Fig. 2) were performed manually using sterile surgical scissors, including no-de-leafing (D1), de-leafing leaving 15 cm of foliage from the top (D2), and de-leafing leaving 25 cm leaf from the top (D3) and were evaluated under different holding treatments in experiment 2. The leaves present on harvested cut stems (45 cm) were removed after 15 and 25 cm from the apical portion. The replication was performed thrice, including ten cut flowers per replication in each treatment. Different observations were recorded on every other day for both experiments, including the amount of solution consumed (mL), days to first floret opening (days), flower diameter (cm), vase life (days), leaf appearance (yellowing), and overall appearance (flower and leaf). The scores of flowers and leaf appearance (observed visually at 0, 3, 6, 9, 12, and 14 days interval) were added to evaluate overall presentability and final scoring was done out of 100 (9).

Statistical analysis

Data regarding various pulsing and holding treatments were analysed via SPSS version 16.0 software (11). The first experiment was statistically analysed under a completely randomized block design and a factorial completely randomized block design was used in the second experiment at a 5 % level of significance. The means were compared based on least significant difference (LSD) at the 0.05 level. Moreover, the correlation analysis was computed between vase life and various flowering characteristics using R Studio (12).

Fig. 1. Harvesting stage of godetia.

Fig. 2. De-leafing of cut stems (D_2: De-leafing 15 cm from top ; D_3:De-leafing 25 cm from top).

Results and Discussion

The mean data obtained from both pulsing and holding experiments showed significant improvement in various characteristics, such as longevity, floret and leaf appearances of godetia cut flowers.

Impact of different pulsing treatments in improving the postharvest life of godetia (*Clarkia amoena*) cut flowers

In the first experiment, the data presented in Table 1 revealed that 6 hr pulsed cut flowers consumed the maximum amount of pulsing solution (28 mL) under the treatment combination of 8-HQC (200 mg/L) + BA (15 mg/L). The Fig. 1 illustrates solution uptake differences between treatments, demonstrating that chemical preservatives significantly enhance solution absorption capacity compared to controls, which directly affects commercial cut flower handling. While the exogenous application of sucrose (4 %) + 8-HQC (300 mg/L) + BA (15 mg/L) for 6 hr resulted in improvement of morphological (petals and leaf appearance) and physiological (solution uptake, transpiration) characters of cut flowers. The earliest florets opening (3.87 days) was obtained in 6 hr pulsed cut flowers under treatment containing sucrose (4 %) + 8-HQC (300 mg/L) + BA (15 mg/L). The treatment comprising sucrose appeared to be an essential remedy to facilitate flower opening (Fig. 3) much sooner than other treatments (13). The florets opening of untreated cut stems was delayed (6.67 days). It is due to 8-HQC, which is well known to enhance solution uptake by reducing microbial development in vascular bundles and increasing cut flowers ability to absorb more solution (14, 15). This was in contrast to the control, which only consisted of distilled water. It was reported that the stems placed in the standard preservatives comprising sugar may act as a vital part in moving water to the inflorescence due to the potential scarcity of carbohydrates resulting from stem cutting (16) .

Floret diameter (6.27 cm) of godetia on pulsing for 6 hr. with sucrose (4 %) + 8-HQC (200 mg/L) + BA (15 mg/L) exhibited a significant increase of 19 % in contrast to un-pulsed cut flowers (5.25 cm). It was found statistically at par with the solution mixture of sucrose (4 %) + 8-HQC (300 mg/L) + BA (15 mg/L), revealing a 6.16 cm flower diameter. Table 2 shows the comparative effectiveness of different treatment combinations on floret diameter, providing clear evidence of economically viable options for commercial floriculture applications. It may be due to the accumulation of translocated sugars in floral tissue, which helps in increasing their somatic concentration and capacity to absorb water and sustain turgidity. Further, sucrose extends flower life and increases the number of open florets in contrast to flowers maintained in distilled water (17).

Table 1. Effect of pulsing treatments on postharvest characteristics of *Clarkia amoena* cut flowers

Pulsing Treatments	Amount of pulsing solution consumed (mL)	Number of days taken to complete florets opening of the cut stem	Floret diameter (cm)	Vase Life (days)
8-HQC[1] (200 mg/L) + BA[2] (15 mg/L) for 2 hr	14.00^{e}	6.47^{ab}	5.63^{cde}	10.93^{h}
8-HQC (200 mg/L) + BA (15 mg/L) for 4 hr	19.00^{c}	6.07^{c}	5.54^{def}	11.73^{fg}
8-HQC (200 mg/L) + BA (15 mg/L) for 6 hr	28.00^{a}	5.33^{de}	5.53^{def}	12.53^{d}
8-HQC (300 mg/L) + BA (15 mg/L) for 2 hr	12.67^{ef}	6.32^{abc}	5.40^{ef}	11.40^{g}
8-HQC (300 mg/L) + BA (15 mg/L) for 4 hr	18.33^{cd}	6.07^{c}	5.32^{ef}	12.53^{d}
8-HQC (300 mg/L) + BA (15 mg/L) for 6 hr	25.33^{b}	5.27^{e}	5.78^{bcd}	13.07^{c}
Sucrose (4 %) + 8-HQC (200 mg/L) + BA (15 mg/L) for 2 hr	8.67^{g}	6.14^{bc}	6.01^{ab}	12.27^{de}
Sucrose (4 %) + 8-HQC (200 mg/L) + BA (15 mg/L) for 4 hr	13.00^{ef}	5.67^{d}	6.10^{ab}	13.60^{b}
Sucrose (4 %) + 8-HQC (200 mg/L) + BA (15 mg/L) for 6 hr	18.67^{cd}	4.07^{f}	6.27^{a}	13.80^{b}
Sucrose (4 %) + 8-HQC (300 mg/L) + BA (15 mg/L) for 2 hr	6.33^{h}	6.30^{bc}	6.07^{ab}	12.00^{ef}
Sucrose (4 %) + 8-HQC (300 mg/L) + BA (15 mg/L) for 4 hr	11.67^{f}	5.37^{de}	5.94^{abc}	13.93^{ab}
Sucrose (4 %) + 8-HQC (300 mg/L) + BA (15 mg/L) for 6 hr	17.33^{d}	3.87^{f}	6.16^{a}	14.20^{a}
Control (distilled water)		6.67^{a}	5.25^{f}	9.83^{i}

The values in each column that are preceded by same letter are not significantly different from one another ($p \leq 0.05$); 8HQC[1]- 8-Hydroxy-quinone citrate; BA[2]- Benzyl adenine

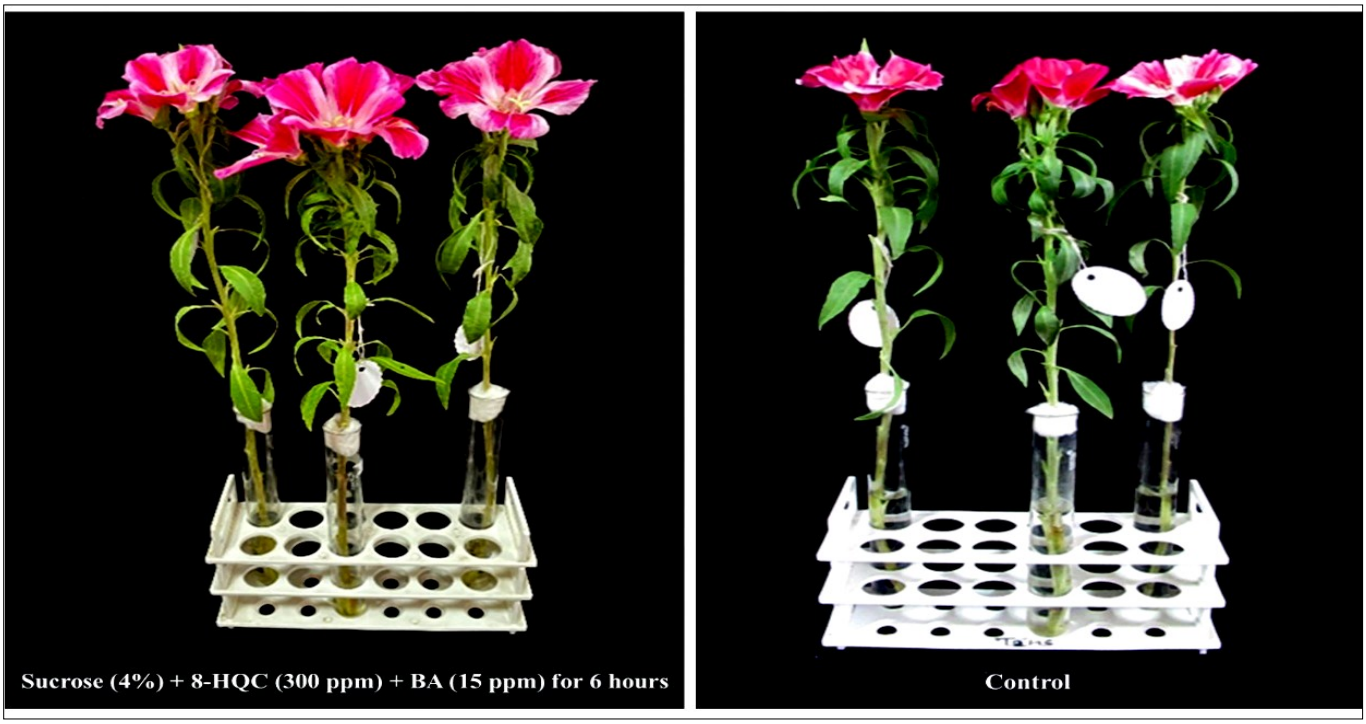

Fig. 3. Effect of pulsing treatments on days taken to complete florets opening (4 days after pulsing).

Greater water uptake results in a larger flower diameter and extended vase life.

The freshly harvested godetia cut stems, pulsing for 6 hr with sucrose (4 %) + 8-HQC (300 mg/L) + BA (15 mg/L), exhibited 44 % greater longevity (14.20 days) over control flowers (9.83 days). The postharvest solutions that comprise a source of carbohydrate (sucrose or glucose) have the ability to delay senescence of cut flowers and enable young buds to develop to maturity, thereby extending the vase life of the stems. Exogenous cytokinin (BA) used in pulsing solution helps diminish water stress injury, respiration rate and ethylene sensitivity (18).

Effect of pulsing treatments on the presentability of godetia (Clarkia amoena) cut stems

The data pertaining to the overall presentability of godetia cut flowers in Table 2 shows a significant difference in score (out of 100), which was obtained due to different pulsing treatments. The Fig. 4 demonstrates the visual differences in presentability among treatments, clearly showing that the optimized chemical formulation maintains aesthetic appeal for commercial applications. The flower presentability (Fig. 4) appeared to be enhanced with a score of 87.91 under 6 hr of pulsed cut flowers in a treatment consisting of sucrose (4 %) + 8 -HQC (300 mg/L) + BA (15 mg/L). The scores obtained regarding overall presentability on the basis of flower freshness and colour were significantly higher than unpulsed cut flowers (80.39 points out of 100).

The data in Table 2 depicting leaf yellowing revealed that the cut flowers treated with sucrose (4 %) solutions were observed with slight leaf yellowing, in contrast to the cut stems kept in non-sucrose solutions. The untreated cut stems scored 3.31 out of 5, while treatments resulted in a lower score than the control, which was due to the adverse impact of sucrose

Fig. 4. Experimental setup of pulsed cut stems.

Table 2. Effect of pulsing treatments on the overall presentability of *Clarkia amoena* cut flowers

Pulsing treatments	Leaf yellowing (scoring out of 5)	Overall presentability (Scoring out of 100)
8-HQC (200 mg/L) + BA (15 mg/L) for 2 hr	3.71^{ab}	85.30^{bc}
8-HQC (200 mg/L) + BA (15 mg/L) for 4 hr	3.79^{a}	85.41^{bc}
8-HQC (200 mg/L) + BA (15 mg/L) for 6 hr	3.56^{cd}	83.3^{d}
8-HQC (300 mg/L) + BA (15 mg/L) for 2 hr	3.63^{bc}	85.87^{b}
8-HQC (300 mg/L) + BA (15 mg/L) for 4 hr	3.48^{d}	84.19^{cd}
8-HQC (300 mg/L) + BA (15 mg/L) for 6 hr	3.49^{d}	83.17^{d}
Sucrose (4 %) + 8-HQC (200 mg/L) + BA (15 mg/L) for 2 hr	3.18^{f}	86.63^{ab}
Sucrose (4 %) + 8-HQC (200 mg/L) + BA (15 mg/L) for 4 hr	3.18^{f}	85.92^{b}
Sucrose (4 %) + 8-HQC (200 mg/L) + BA (15 mg/L) for 6 hr	3.03^{g}	85.89^{b}
Sucrose (4 %) + 8-HQC (300 mg/L) + BA (15 mg/L) for 2 hr	3.08^{fg}	86.37^{b}
Sucrose (4 %) + 8-HQC (300 mg/L) + BA (15 mg/L) for 4 hr	3.08^{fg}	86.44^{ab}
Sucrose (4 %) + 8-HQC (300 mg/L) + BA (15 mg/L) for 6 hr	3.10^{fg}	87.91^{a}
Control (distilled water)	3.31^{e}	80.39^{e}

The values in each column that are preceded by same letter are not significantly different from one another (p≤0.05)

(4 %). This might be due to the leaves of BA-treated cut stems, which remained green, vigorous, and due to cytokinin's property to inhibit leaf senescence/yellowing. Use of cytokinins also showed less postharvest losses and application of BA contributed to reducing leaf yellowing caused by sucrose in the vase solution (19, 20)

Impact of different holding and de-leafing treatments on improving the postharvest life

In the second experiment, various holding solutions and de-leafing treatments were found significantly beneficial in improving the postharvest life of cut flowers in contrast to the control, as depicted in Table 3. Fig. 5 presents the comparative effects of these treatments, demonstrating the industrial applicability of these findings for enhancing cut flower shelf life in commercial settings.

Cut spikes consumed the maximum amount of holding solution (85.02 mL) when placed in a solution comprising 8-HQC (100 mg/L) + BA (10 mg/L), in contrast to the control, with only 56.84 mL uptake of distilled water. Also, the de-leafed cut stems, leaving 15 cm from the top (D2), revealed maximum solution uptake (74.01 mL). The interaction between holding and de-leafing treatments significantly affected holding solution consumption. The different studies illustrated that an increase in water uptake may be due to the presence of 8-HQC and BA. Further, the use of exogenous cytokinin for cut stems may also enhance water uptake and lower the degradation resulting from water stress by preventing leaf yellowing and chlorophyll loss (21).

Regardless of solution consumption by cut stems, it is evident from the data presented in Table 3 that the number of days taken to complete florets opening were found significantly lower (3.78 days) in solution consisting sucrose (2 %) + 8-HQC (200 mg/L) + BA (10 mg/L) than days taken in distilled water (6.62 days). Moreover, the earliest florets opening was observed in cut stems that were de-leafed after

Table 3. Effect of holding treatments and de-leafing on the vase life of *Clarkia amoena* cut flowers

Holding Treatments	Amount of holding solution consumed (mL)				Number of days taken to complete florets opening of the cut stem (days)				Floret diameter (cm)			
	D1[3]	D2[4]	D3[5]	Mean	D1	D2	D3	Mean	D1	D2	D3	Mean
8-HQC (100 mg/L) + BA (5 mg/L)	77.93	81.4	78.07	79.13^{bcd}	5.33	6.00	5.00	5.44^{bc}	5.18	5.61	5.59	5.46^{ef}
8-HQC (100 mg/L) + BA (10 mg/L)	80.53	89.2	85.33	85.02^{a}	5.00	5.67	5.33	5.33^{bc}	5.89	5.95	6.09	5.97^{bc}
8-HQC (100 mg/L) + BA (15 mg/L)	74.33	87.94	83.73	82.00^{abc}	6.00	5.00	5.33	5.44^{bc}	5.68	5.45	5.8	5.64^{def}
8-HQC (200 mg/L) + BA (5 mg/L)	72.99	82.94	79.32	78.41^{cd}	5.00	5.00	5.00	5.00^{c}	5.98	6.00	5.75	5.91^{bcd}
8-HQC (200 mg/L) + BA (10 mg/L)	80.40	85.80	81.87	82.69^{ab}	5.67	5.67	6.33	5.89^{b}	5.92	5.85	5.38	5.72^{cde}
8-HQC (200 mg/L) + BA (15 mg/L)	73.73	78.53	74.27	75.51^{d}	6.00	5.00	5.67	5.56^{bc}	5.54	5.28	5.4	5.41^{f}
Sucrose (2 %) + 8-HQC (100 mg/L) + BA (5 mg/L)	63.13	64.6	63.33	63.69^{ef}	4.00	4.33	4.33	4.22^{d}	5.97	6.21	6.22	6.14^{b}
Sucrose (2 %) + 8-HQC (100 mg/L) + BA (10 mg/L)	66.93	66.53	66.93	66.80^{e}	4.00	4.00	4.00	4.00^{d}	6.18	6.45	6.67	6.43^{ab}
Sucrose (2 %) + 8-HQC (100 mg/L) + BA (15 mg/L)	62.33	66.00	66.67	65.00^{e}	4.67	4.33	4.00	4.33^{d}	6.08	6.41	6.01	6.17^{a}
Sucrose (2 %) + 8-HQC (200 mg/L) + BA (5 mg/L)	58.67	68.87	63.33	63.62^{ef}	4.33	4.00	4.33	4.22^{d}	6.17	6.14	5.98	6.10^{b}
Sucrose (2 %) + 8-HQC (200 mg/L) + BA (10 mg/L)	62.98	68.93	67.20	66.37^{e}	4.00	3.67	3.67	3.78^{d}	6.02	6.37	5.89	6.09^{b}
Sucrose (2 %) + 8-HQC (200 mg/L) + BA (15 mg/L)	59.33	63.93	59.54	60.94^{f}	4.00	4.00	3.67	3.89^{d}	6.06	5.78	5.98	5.94^{bc}
Control (distilled water)	56.00	57.40	57.13	56.84^{g}	6.67	6.57	6.62	6.62^{a}	5.40	5.25	5.49	5.38^{f}
Mean	68.41^{c}	74.01^{a}	71.29^{b}	-	4.97	4.86	4.87	-	5.85	5.91	5.87	-

[3]No de-leafing; [4]De-leafing leaving 15 cm leaf from top; [5]De-leafing leaving 25 cm leaf from top

Fig. 5. Presentability of cut stems kept in holding solution after 8 days.

leaving 15 cm from the top, when placed in sucrose (2 %) + 8-HQC (200 mg/L) + BA (10 mg/L) solution. The largest floret diameter (6.43 cm) was obtained from treatment sucrose (2 %) + 8-HQC (100 mg/L) + BA (10 mg/L), and the smallest floret diameter (5.38 cm) was seen under control. The certainty that the stems placed in the standard preservatives comprising sugar may be crucial in moving water to the inflorescence, where it is required throughout the flower opening process (22).

The interaction effect of holding and de-leafing treatments on the number of days required for whole floret opening and floret diameter was insignificant. The vase life of godetia cut flowers improved with holding solutions and de-leafing treatments. Treatment T8 significantly improved the vase life (15.33 days) in contrast to T13 (10.01 days), i.e., by 50 % over T13 (Fig. 6). Table 4 presents the complete comparative analysis of all treatment combinations, providing quantitative evidence for practical applications in commercial floriculture.

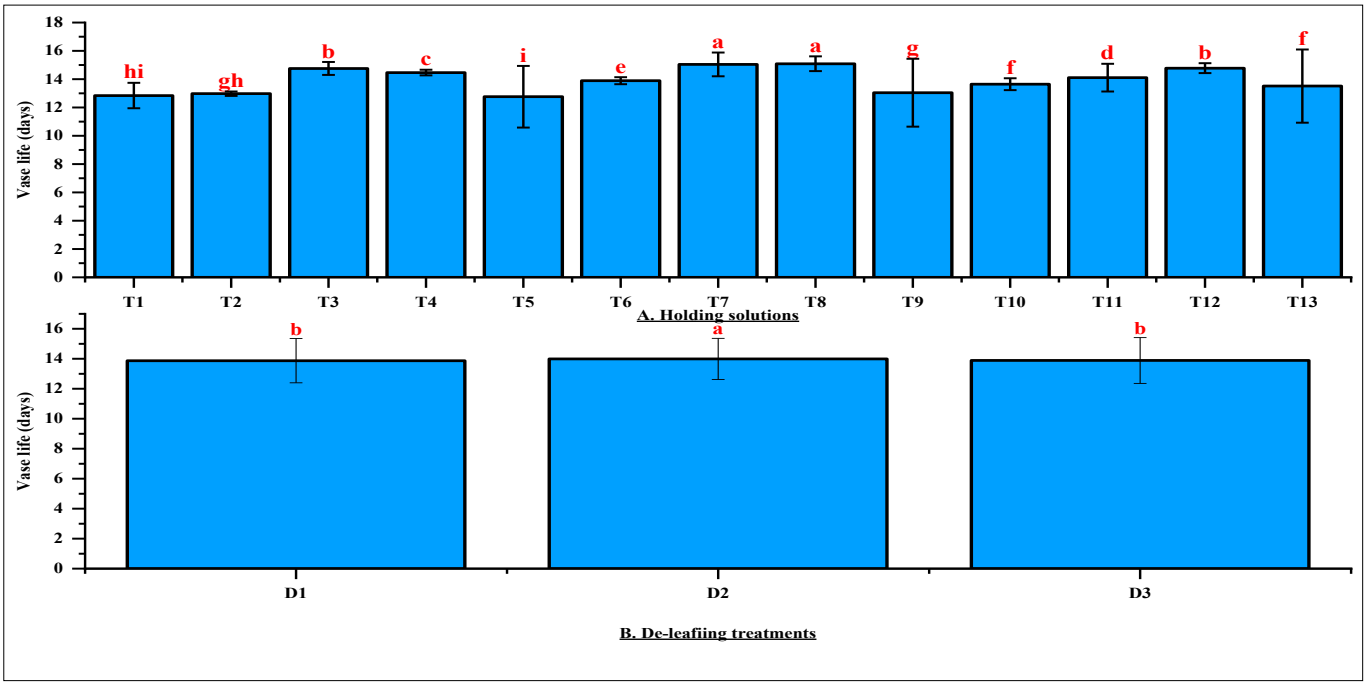

Fig. 6. Mean comparison of vase life (days) after placing godetia (*Clarkia amoena*) cut stems in various holding solutions (A) and de-leafing treatments (B), error bars with the same alphabets were statistically at par with respect to p ≤ 0.05 level of significance [A- Holding solutions: T1 (8-HQC (100 mg/L) + BA (5 mg/L)), T2 (8-HQC (100 mg/L) + BA (10 mg/L)), T3 (8-HQC (100 mg/L) + BA (15 mg/L)), T4 (8-HQC (200 mg/L) + BA (5 mg/L)), T5 (8-HQC (200 mg/L) + BA (10 mg/L)), T6 (8-HQC (200 mg/L) + BA (15 mg/L)), T7 (Sucrose (2 %) + 8-HQC (100 mg/L) + BA (5 mg/L)), T8 (Sucrose (2 %) + 8-HQC (100 mg/L) + BA (10 mg/L)), T9 (Sucrose (2 %) + 8-HQC (100 mg/L) + BA (15 mg/L)), T10 (Sucrose (2 %) + 8-HQC (200 mg/L) + BA (5 mg/L)), T11 (Sucrose (2 %) + 8-HQC (200 mg/L) + BA (10 mg/L)), T12 (Sucrose (2 %) + 8-HQC (200 mg/L) + BA (15 mg/L)), T13 (Control (distilled water); B- De-leafing treatments: D1 (no-deleafing), D2 (de-leafing 15 cm from top) and D3 (de-leafing 25 cm from top)].

Among defoliated treatments, removing leaves while retaining the top 15 cm (D2) resulted in the longest vase life (14.31 days). Meanwhile, the interaction effect of T8D2 (sucrose (2 %) + 8-HQC (100 mg/L) + BA (10 mg/L) along with de-leafing 15 cm from top) showed highest vase life (15.67 days) while it was minimum in control treated cut stems with no-deleafing as depicted in Fig. 7 Longevity and early florets opening of cut stems may be due to reduction in transpiration after de-leafing and adequate source of carbohydrate enabling young buds to develop early (23). In addition, continual sucrose significantly improved floral bud opening and flowering lifespan (24). Also, maintaining solution pH conditions with longer stability will further reduce micro-organisms growth, henceforth desirable water status for cut stems (25).

Effect of holding and de-leafing treatments in enhancing presentability

The data related to the improvement in the presentability of cut spikes are presented in Table 4. Fig. 8 illustrates the visual quality differences between treatments, providing clear evidence that optimized chemical preservation methods significantly enhance the marketable quality of cut flowers, which directly impacts commercial value. The overall presentability of cut stems (Fig. 5 & 8) with the highest score (88.37 out of 100) obtained from a solution consisting of sucrose (2 %) + 8-HQC (100 mg/L) + BA (10 mg/L) over the control. The presentability of godetia cut flowers was assessed based on freshness and colour characteristics, respectively. Also, the highest score (87.12) of cut stems was observed when leaves were de-leafed, leaving up to 15 cm from the top and the lowest score (85.79) was found in non-de-leafed cut stems. Previous studies have investigated the impact of sugars on floral freshness maintenance. Using 8-HQC reduces vascular blockage (caused by bacterial development), allowing greater solution absorption in flowers and extending the freshness of cut flowers (26).

The leaf yellowing score was the lowest, indicating maximum yellowing in the solution containing sucrose (2 %). However, the cut stems placed under non-sucrose comprising treatments appeared with the least leaf yellowing (27). To de-leafed cut stems, it was also reported that the florets on defoliated shoots (10 cm leaves removed) reacted to a preservative solution better than those with leafy shoots. Also, a limited number of leaves on shoots promoted an appropriate balance between carbohydrates and hormonal distribution (28).

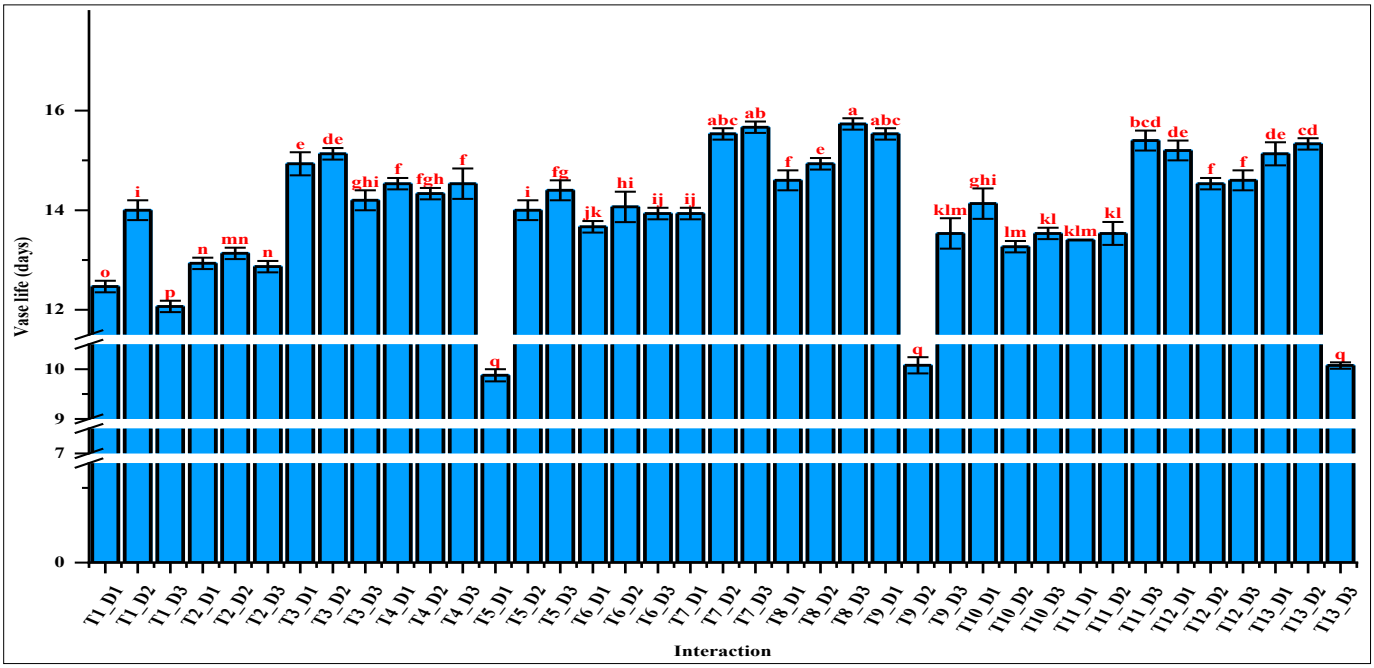

Fig. 7. Mean comparison of vase life (days) with respect to the interaction effect of different holding and de-leafing treatments (Error bar with same alphabets are statistically at par according to p ≤ 0.05 level of significance).

Table 4. Effect of holding treatments and de-leafing on leaf yellowing and overall presentability of *Clarkia amoena* cut flowers

Holding Treatments	Leaf yellowing (scoring out of 5)				Overall presentability (scoring out of 100)			
	D1	D2	D3	Mean	D1	D2	D3	Mean
8-HQC (100 mg/L) + BA (5 mg/L)	3.45	3.67	3.51	3.54^{a}	83.69	85.85	84.8	84.78^{e}
8-HQC (100 mg/L) + BA (10 mg/L)	3.51	3.6	3.62	3.58^{a}	85.08	88.11	87	86.73^{bcd}
8-HQC (100 mg/L) + BA (15 mg/L)	3.43	3.48	3.48	3.46^{ab}	84.28	84.58	85.26	84.7^{e}
8-HQC (200 mg/L) + BA (5 mg/L)	3.42	3.58	3.45	3.49^{a}	85.07	86.69	84.02	85.26^{de}
8-HQC (200 mg/L) + BA (10 mg/L)	3.47	3.62	3.6	3.56^{a}	86.44	84.85	86.87	86.05^{cde}
8-HQC (200 mg/L) + BA (15 mg/L)	3.22	3.65	3.35	3.41^{ab}	84.07	85.63	85.19	84.96^{e}
Sucrose (2 %) + 8-HQC (100 mg/L) + BA (5 mg/L)	2.75	2.89	3.08	2.91^{c}	86.91	89.35	88.66	88.31^{a}
Sucrose (2 %) + 8-HQC (100 mg/L) + BA (10 mg/L)	2.79	3.11	2.97	2.96^{c}	86.83	89.45	88.82	88.37^{a}
Sucrose (2 %) + 8-HQC (100 mg/L) + BA (15 mg/L)	2.99	3.13	3	3.04^{c}	87.81	89.19	87.02	88.01^{ab}
Sucrose (2 %) + 8-HQC (200 mg/L) + BA (5 mg/L)	2.87	3.02	2.94	2.94^{c}	87.98	87.5	86.43	87.3^{abc}
Sucrose (2 %) + 8-HQC (200 mg/L) + BA (10 mg/L)	3.09	3.08	3.1	3.09^{c}	87.83	89.07	87.61	88.17^{ab}
Sucrose (2 %) + 8-HQC (200 mg/L) + BA (15 mg/L)	2.98	3.16	2.99	3.04^{c}	88.26	88.31	87.48	88.02^{ab}
Control (distilled water)	3.13	3.63	3.13	3.30^{b}	80.96	83.95	81.24	82.05^{f}
Mean	3.16^{b}	3.36^{a}	3.25^{b}	-	85.79^{b}	87.12^{a}	86.18^{b}	-

Fig. 8. Experimental setup of godetia cut flowers (*Clarkia amoena)* in holding solution.

Correlation analysis of postharvest attributes with vase life in de-leafed godetia stems

Data of Fig. 9 revealed strong positive and weak negative correlations among different postharvest characteristics to vase life of godetia cut stems, de-leafing after leaving 15 cm from the top. The bar graph represents correlation values, with strong positive correlations in dark blue and weak negative correlations in dark red, ranging from -1 to +1. On interpretation, it is clear that VLD2 had a strong positive correlation with FDD1 (0.96), FDD2 (0.97), FDD3 (0.95), VLD1 (0.99), VLD3 (1.00), OPD1 (0.99), OPD2 (0.97) and OPD3 (1.00). In contrast, it was strongly negative correlated with FFOD1 (-0.98), FFOD2 (-0.98), FFOD3 (-0.98), LYD2 (-0.94), LYD1 (-0.87) and LYD3 (-0.84), while it was weakly negative correlated with AHSD1 (-0.69), AHSD2 (-0.66) and AHSD3 (-0.67). The unfavourable leaf discoloration will reduce the freshness and visual appeal of cut stems, which mainly occurs due to poor solution uptake, causing water stress and ultimately contributing to senescence along with leaf yellowing or browning (29). Meanwhile, the treatment combination that slowed the flower opening metabolism was considered optimum for better quality and longevity of cut stems (30).

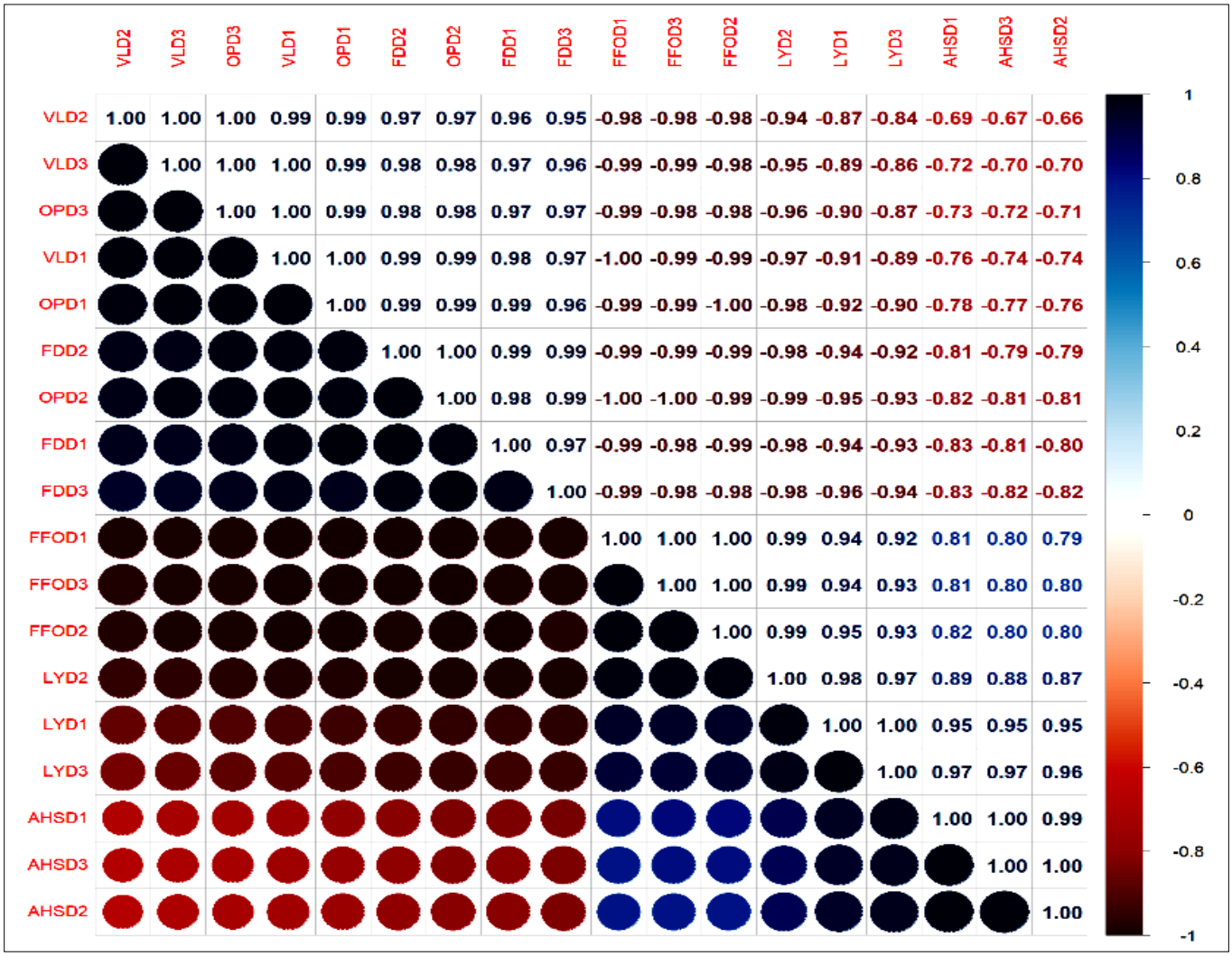

Fig. 9. Correlation analysis of postharvest attributes of *Clarkia amoena* affected by different holding and de-leafing treatments (AHS-Amount of holding solution consumed; FFO– Days taken to first floret opening; FD– Flower diameter; VL– Vase life; LY– Leaf yellowing; OP– Overall presentability; D1– No de-leafing; D2 - De-leafing after leaving 15 cm from top; D3– De-leafing after leaving 25 cm from top) (Darker the colour, greater the correlation intensity).

Study limitations

While our experiments demonstrate significant improvements in the postharvest life of godetia cut flowers, several limitations must be acknowledged. The experiments were conducted on small volumes using analytical-grade reagents, which may not directly translate to large-scale commercial applications. The cost-effectiveness of these treatments at an industrial scale requires further investigation. Additionally, the transferability of these findings to other flower species cannot be guaranteed without additional experimentation.

Future research directions

1) Scaling studies to validate the commercial viability of the most promising treatments. 2) Economic analyses comparing treatment costs against increased market value. 3) Development of automated application systems for optimized chemical solutions. 4) Testing these preservation methods across diverse flower species to establish broader applicability. 5) Integration with artificial intelligence-based predictive maintenance systems for optimizing treatment timing and dosage. 6) Investigation of environmentally sustainable alternatives to chemical preservatives.

Modern computing methods and artificial intelligence can help solve multifactorial techno-economic problems in flower preservation technology. Recent research demonstrates that digital twin simulation modelling and AI-based Internet of Manufacturing Things systems can predict the commercial success of complex technologies like those presented in this study. Such approaches could optimize treatment parameters and forecast the market performance of preserved cut flowers across different market conditions.

Conclusion

This manuscript presents the positive impact of various pulsing and holding solutions in improving the postharvest life of godetia (*Clarkia amoena*) cut flowers. Since the cut flowers presentability is the most important criterion in floriculture trade, both nationally and internationally. Therefore, pulsing and holding solutions in the recommended proportion can further improve their presentability. The induction of yellowing in leaves (major concern in godetia) due to sucrose can be encountered via varied concentrations of cytokinin's growth regulator, which further offers new possibilities.

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Authors' contributions

SB and PS[1] framed out the research work and designing of the experiment. VB and SP carried out the field work and lab experiment. VB and PS[2] further documented the data, performed the statistical analysis and drafted the manuscript. All listed authors have thoroughly reviewed and endorsed the final version of the manuscript, indicating their collective agreement with its content and findings.

[PS[1] refers to Puja Sharma and PS[2] refers to Panchal Sangmesh]

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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