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Effects of paclobutrazol and gibberellin A3 in combination with calcium chloride and 8-HQ on increasing the vase life of cut rose

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Abstract

The cut rose, a globally traded ornamental flower, is highly perishable due to issues such as vascular blockage, inadequate water absorption, neck bending, petal discoloration, disease, and senescence. Prolonging the vase life of cut roses is crucial for enhancing their commercial value, and the use of preservatives in vase solutions has proven effective in achieving this goal. In this study, the 'Samourai' variety of *Rosa hybrida*, characterized by standard-type red flowers and widespread international trade, was used to assess the effects of plant growth regulators on delaying senescence and extending vase life Treatments included: (T1) Paclobutrazol (100 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%), (T2) Paclobutrazol (100 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), (T3) GA_3 (75 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), (T4) GA_3 (75 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%), and a control with distilled water. Paclobutrazol treatments effectively delayed flower opening, and also 8-HQ treatments inhibited bacterial growth in the vase solutions. The highest fresh weight and total solution uptake were observed in the T2 treatment. Minimal color changes occurred in treatments containing paclobutrazol compared to the control, which exhibited the most pronounced discoloration. Overall, the combination of paclobutrazol, 8-HQ, and sucrose demonstrated the most significant effect in prolonging the vase life of cut roses, providing valuable insights for enhancing postharvest management in the floriculture industry. By enhancing the longevity and quality of cut flowers, this approach contributes to reducing postharvest losses and supports economic sustainability for growers and retailers. Future studies could focus on refining the concentration and application methods of these treatments, also investigating their effects on various rose cultivars and other commercially important cut flowers. Additionally, assessing the long-term environmental impacts and cost-effectiveness of these solutions would further aid in establishing best practices for large-scale implementation.

Keywords: Cut rose, Paclobutrazol, GA_3, 8-HQ

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INTRODUCTION

The postharvest longevity of cut flowers plays a pivotal role in their marketability and consumer appeal, as buyers prioritize high-quality blooms with extended vase life (Reid and Jiang, 2012). For cut roses, plant growth regulators have been explored as an effective approach to enhance their vase life. Roses are popular cut flowers, are known for its short vase life, which can be a significant challenge for growers and distributors (Reid, 2005). The main factors that shorten the vase life of cut roses include water loss, microorganisms causing vascular congestion and the negative effects of ethylene. In cut flowers, senescence refers to the final stage of the flower's life cycle and results in wilting, defoliation and loss of quality. This process can be accelerated by loss of cell function and reduced nutrient and water uptake. Vascular congestion is a condition in which water and nutrients cannot be transported properly through the vessels in the flower stems. This blockage can be caused by air bubbles, microbial growth or physical obstructions and prevents the flower from taking up water, leading to wilting. Both senescence and vascular congestion are important factors that directly affect the freshness of cut flowers. Plant growth regulators, especially cytokinins, gibberellins, and ethylene inhibitors, can be used to reduce these effects. Research has shown that growth hormones and antimicrobial agents can extend vase life by increasing water retention, reducing microbial clogging and suppressing ethylene synthesis (Reid and Jiang, 2012; van Doorn and Woltering,

2008). The use of such regulators with the right concentration and application methods can increase the commercial value of cut flowers. By understanding the physiological and biochemical processes involved in flower opening and senescence, researchers can develop targeted strategies to prolong the vase life of this important cut flower. Maintaining the postharvest quality and extending the vase life of cut flowers is a critical challenge in the floriculture industry. Various pre- and post-harvest treatments have been investigated to address this issue. One promising approach is the use of plant growth regulators and chemical treatments (Gul et al., 2014).

Paclobutrazol, a plant growth retardant, is recognized for its ability to delay senescence, and also Paclobutrazol, as a gibberellin synthase inhibitor, delays the ageing process of flowers. This slows down the flower's metabolic activities, postponing signs of ageing and keeping it fresher for longer. Gibberellic acid is a hormone that promotes flower development and can improve quality, especially in the early developmental stages, by making flowers open faster. Gibberellic acid also facilitates the transport of water and nutrients to feed the leaves of plants and flowers, which improves vase life, and calcium chloride enhances postharvest quality (Sharma and Thakur, 2020; Toyohara et al., 2020; Gul et al., 2014). Optimal concentrations of paclobutrazol effectively extend the vase life of cut flowers by delaying petal senescence and preserving flower quality (Toyohara et al., 2020). Similarly, gibberellic acid, particularly when applied as a stem dip, has been shown to support tepal development and extend the ornamental lifespan, especially when combined with short-term dry storage. Calcium chloride ($CaCl_2$) has also been widely reported to improve the vase life of cut flowers by enhancing structural integrity and reducing senescence (van Doorn, 2012; Nair et al., 2003). The use of sugar to prolong the vase life of cut flowers contributes to maintaining cell structure and supporting respiratory processes by meeting the energy requirements of the flowers. The sugar solution increases the water uptake of the flowers and maintains the turgor pressure, thus keeping the flowers fresher for longer (Seyed Hajizadeh et.al. 2024).

This study investigates the combined effects of paclobutrazol, gibberellic acid, and calcium chloride on extending the vase life of cut roses.

MATERIALS AND METHODS

The studies were conducted at Bingol University's Department of Horticulture (38°53'59.34"N, 40°29'15.95"E) (Google Maps 2024). In May 2024, cut flowers of *Rosa* × *hybrida* cv. 'Samourai' were supplied by a commercial farm located in Şanlıurfa, Türkiye, and pre-cooled for six hours at 4°C immediately after harvest. They were then moved to the Department of Horticulture at Bingol University's vase life room in a dry atmosphere. The blossoms were recut to a length of 40 cm on the stems. Four treatments were included in the randomized complete blocks design (RCBD) experiment.

In addition to the control, the following treatments were given Table 1. Every solution was prepared freshly at the onset of the experiment. Vase solutions (750 ml) were put into a 1000 ml vase containing the cut flowers. There were five replicas of each treatment, each with three flowers. As a control, distilled water was utilized. The temperature in the vase life room was 21 ± 2°C, with a relative humidity of 60 ± 5% and 1000 lux of light.

Table 1. Preservative treatments applied for extending vase life to cut roses

Treatments	Vase solution composition
Control	Distilled water
T1	Paclobutrazol (100 mg L^{-1}) +$CaCl_2$ (5 g L^{-1}) + Sucrose (1%)
T2	Paclobutrazol (100 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%)
T3	GA_3 (75 mg L^{-1}) +8-HQ (200 mg L^{-1}) + Sucrose (1%)
T4	GA_3 (75 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%)

Flower Opening Rate (FOR)

The bud diameter was measured every three days from day 0 for up to 6 days in order to determine the flower opening rate. An equation of (Li et al., 2021) was adjusted to estimate the ratio of flower opening (Equality 1.)

$$\text{FOR}\ (\%) = \frac{\text{Flower diameter on the dn} - \text{Flower diameter on the dn}-1}{\text{Flower diameter on the d0}} \text{x}100 \quad (1)$$

n: 0,3,6 the end of the measurement

Flower Color Senescence

Color variations were recorded from the first to the last day, and CIELAB values were calculated using a colorimeter (Lovibond; Spectrophotometer a sphere, Serie SP60).

The CIE L^*, a^*, and b* color space system was used to gather measurements, and the a* and b* values were used to determine the hue angle ($h°$) (Equality 2.) and chroma values (C^*) (Equality 3.)

$(h° = 180 + \tan^{-1}(b^*/a^*))$ 2)

$[C^* = (a^{*2} + b^{*2})1/2]$ (3)

Stem Firmness

Three flowers were chosen randomly for every treatment. After the control treatment's vase life ended, firmness was assessed using a TA-TX Plus Texture Analyser (Stable Micro System Ltd., Surrey, UK). The reading was recorded in N (Newton, kg m s^{-2}) when the 2 mm diameter drill probe was drilled 5 mm deep and at a speed of 0.80 mm/s, precisely 3 cm below the cut rose stem.

Relative Fresh Weight

Using an analytical balance, the combined weight of the vase, the treatment fluid, and the cut flowers was determined. The cut flowers were removed from the vase and placed one at a time on the top of the vase to determine their weight. The vase was then swiftly weighed, and the measured flowers were then put back into the treatment solution. The entire weight

of the removed cut flowers in the vase was used to determine the fresh weight of the cut flowers. The formula for calculating the relative fresh weight (%) of the cut flowers was (fresh weight on a given day / fresh weight on day 1) × 100.

Vase Life

The period between the setup of the cut flower vases in the environmentally controlled room and the end of the vase life was used to calculate the vase life. Daily observations were made of the morphological changes in the cut flowers. Every days, assessments of the vase life were carried out in compliance with the modified cut rose evaluation. In summary, when at least three of the five florets displayed one or more of the following signs of senescence, the cut flowers were deemed to have reached the end of their vase life: bending of the pedicel (bent-neck; neckangle 45%), wilting (50% petal turgorloss), bluing (50% blue petals), petal abscission (drop of three or more petals), and leaf abscission and yellowing (50% leaf drop and yellowing).

Bacterial Counts

Following the insertion of the stems into the vase, the amount of bacteria found in the treatment solution was quantified on day 15. From the vase, ten milliliters of the treatment solution were removed, and it was diluted three times and one hundred times. Plate Count Agar plates were covered with liquid (Balestra et al., 2005). The number of bacterial colonies was counted following two days of incubation at 37 °C in a sterile incubator set to a constant temperature.

EC and pH Changes in Vase Solutions

A pH/ORP meter (HI 2211 HANNA Instruments RI/USA) was used to monitor the pH of the solutions and a Conductivity Benchtop (Orion 3-Star, Thermo Scientific) was used to measure the electrical conductivity (EC) every six days.

Statistical Analysis

A completely randomized design with four replications was used to set up a split-plot in time experiment. One way ANOVA was used to examine the flower opening rate (FOR), vase life, bacterial count and stem firmness, two way ANOVA was used *CIELAB* color values, and SPSS software (version 19.0) was used to compare the means using Tukey's test ($P \leq 0.05$).

RESULTS

Flower Opening Rate (FOR)

In all treatments, FOR of cut flowers increased during the first 6 days. The highest value was observed in the control treatment during 6 days. The first 3 days and also the second 3 days of the T2 treatment had the lowest rate, followed by the T1 treatment (Figure 1). Hence, the flower opening rate decreased in combinations containing paclobutrazol.

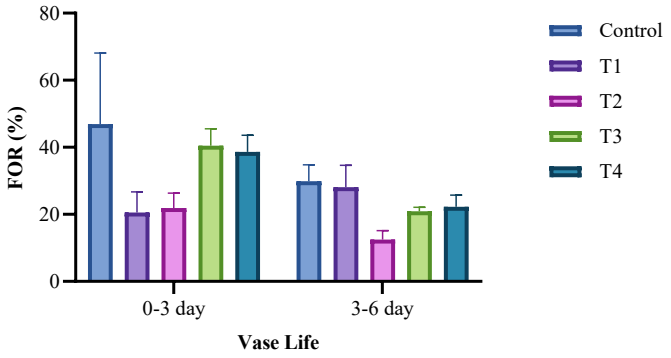

Figure 1. Flower opening rates of cut rose flowers of different vase solution combinations ($P \leq 0.05$). One-way ANOVA results examining the influence of cultivation method and measurement day for vase life on the FOR (%) (T1: Paclobutrazol (100 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%), T2: Paclobutrazol (100 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), T3: GA_3 (75 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), T4: GA_3 (75 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%))

Flower Color Senescence

A colorimeter was used to quantify the colour of each cultivar using the adaxial side of each fresh petal measured during vase life (day 0, day 6, day 12). Petal color was measured using the CIE *L*a*b** colour space: The values of *a** are red (positive) and green (negative); *b** are yellow (positive) and blue (negative); *C*,* colour chroma (higher values indicate increased brightness); *h°* angle, the hue angle of the colour between 0 and 360 (van Doorn et al., 1989). *L*,* the lightness of the colour, ranges from 0 (black) to 100 (white). Each rose was viewed through a different solution, the colours were perceived differently. The lightness (*L**) of most roses changed during the vase life. Other variations in *L* a* b** values were seen in the study throughout the vase life of cut red roses. The fresh rose colour has a high luminosity or brightness, which is why the 'Samourai' rose flowers had a high *L** value on day 0. The color became dull and the *L** value decreased in all treatments, including the control, when the flower was fully withered. In general, the value of some treatments and the control increased as the flower wilted and turned brown, orange, pink or yellow in the last days of its vase life. The *b** value of the cut rose is positive throughout the vase life. Ageing may cause a slight browning or yellowing of the plants. The hue angles (*h°* angle) and *C** values of red roses changed significantly during the vase life for all treatments (Figure 2). The maximum colour change was determined at control though the solutions containing paclobutrazol showed less colour changes.

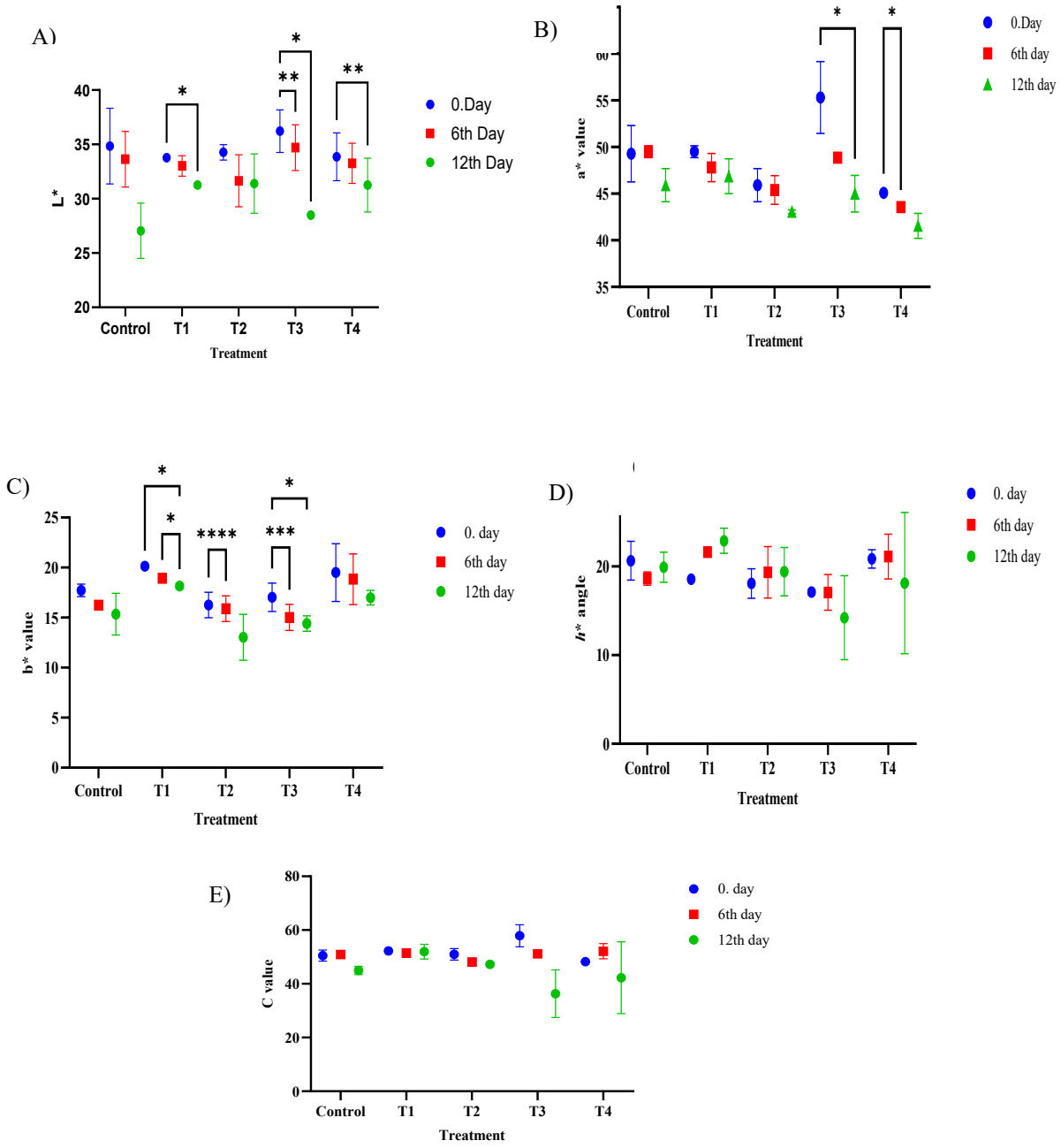

Figure 2. The measurement day for vase life on the *CIELAB* color values in four cut roses L* value (A), a* value (B), b* value (C), *h** angle (D) and *C** values (E). Multiple pairwise comparisons were applied to perform posthoc analysis using the emmeans package in R. The statistical significance is indicated by * ($p < 0.05$), ** ($p < 0.01$), *** ($p < 0.001$), and **** ($p < 0.0001$). It is not significant; ns has not been indicated. (T1:Paclobutrazol (100 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%), T2: Paclobutrazol (100 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), T3: GA_3 (75 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), T4: GA_3 (75 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%))

Vase Life, Total Solution Uptake, Relative Fresh Weight (RFW)

Vase life and total solution uptake of cut roses showed statistically significant differences between T2 treatment and other groups ($P \leq 0.05$). Although control had the shortest vase life (Table 2), T2 treatment had the greatest (13.92 days), 4.25 days longer than the control group (9.67 days). T3 treatment came in second (10.0 days). Similarly with 36.38 ml, the T2 treatment had the highest total solution uptake followed by the control with 25.48 ml (Table 2). Hence, the combination of paclobutrazol and 8-HQ delayed the aging process of 'Samourai' cut flowers and increased their ornamental quality.

Table 2. Vase life and total solution uptake of cut rose flowers of different vase solution combinations

Treatments	Vase Life (day)	Total Solution Uptake (ml)
Control	9.67 b	25.48 b
T1	9.75 b	29.06 ab
T2	13.92 a	36.38 a
T3	10.0 b	25.29 b
T4	9.75 b	23.85 b

($P \leq 0.05$) (T1: Paclobutrazol (100 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%), T2: Paclobutrazol (100 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), T3: GA_3 (75 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), T4: GA_3 (75 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%))

After 'Samourai' branches were added to the glasses, the relative weight of the cut flowers increased for the first three days and then decreased (Figure 3). For the control, T1, T2, T3, and T4 treatments, relative fresh weight peaked on the third day. In addition, the maximum fresh weight was higher for the T1, T2, and T3 treatments than for the control treatment. The highest fresh weight was obtained for the T2 treatment 12.25% higher than the control treatment.

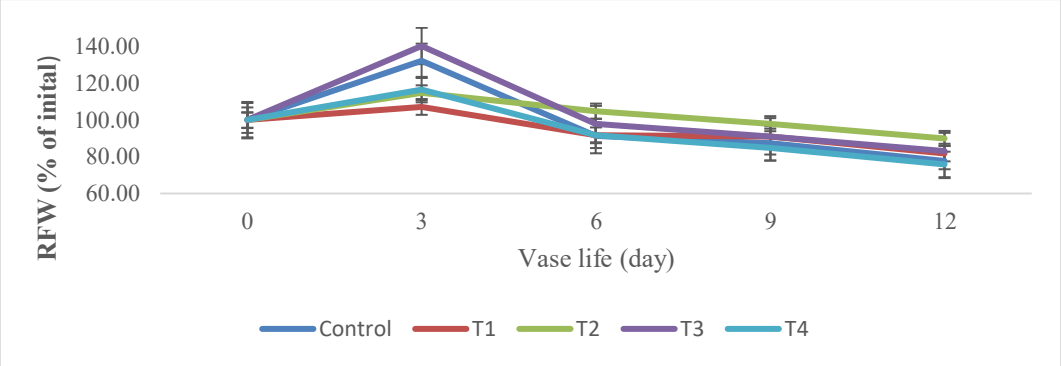

Figure 3. Relative Fresh Weight (RFW) of cut rose flowers of different vase solution combinations ($p \leq 0.05$), (T1: Paclobutrazol (100 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%), T2: Paclobutrazol (100 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), T3: GA_3 (75 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), T4: GA_3 (75 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%))

Bacterial Counts, Stem Firmness

While compared to the control treatment (distilled water), which had the highest total count of bacteria at 6.20 CFU ml^{-1}, the data showed that all treatments decreased the bacterial counts (log_{10} CFU ml^{-1}) of cut rose flowers while using pulsing the vase solution. In addition, compared to the control and the other treatments, the vase solution containing T2 treatment (3.74) and followed by T3 treatment (3.97) had the lowest average bacterial count. Statistically significant differences were not observed in stem firmness of cut rose flowers ($P \leq 0.05$). The highest stem firmness was T2 treatment (23.58 N) followed by T1 treatment (8.10 N) although the lowest stem firmness was control (17.77 N) (Figure 4).

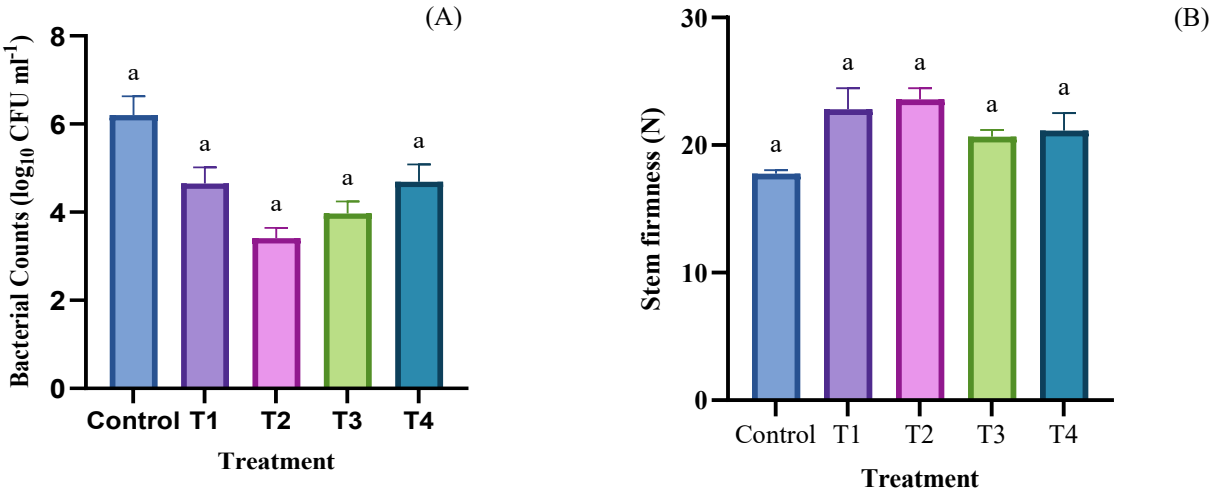

Figure 4. The measurement day for vase life on the Bacterial Count (A) and Stem firmness (B) of cut rose flowers of different vase solution combinations ($P \leq 0.05$), (T1: Paclobutrazol (100 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%), T2: Paclobutrazol (100 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), T3: GA_3 (75 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), T4: GA_3 (75 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%))

EC and Ph Changes in Vase Solutions

In the first 6 days, pH was reduced in the T1 treatment, although pH increased in all other treatments. On the last 12th day of the vase life, pH of all treatments varied between 4.0 and 6.28 (Table 3). The EC values of the treatments varied throughout the vase life. EC values decreased in all treatments, including the control (Table 3).

Table 3. pH and EC variation of different vase solution combinations

Treatment	Day 0		Day 6		Day 12		Variance	
	pH	EC	pH	EC	pH	EC	pH	EC
Control	7.38	260.73	7.25	295.04	6.28	318.67	1.09	-57.93
T1	6.35	7.65	6.56	8.00	6.15	26.58	0.21	-18.93
T2	6.73	13.80	6.15	31.72	5.73	50.45	1.01	-36.65
T3	6.42	20.25	5.76	32.54	5.40	55.60	1.02	-35.35
T4	4.82	7.35	4.42	7.74	4.00	8.49	0.83	-1.14

T1: Paclobutrazol (100 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%), T2: Paclobutrazol (100 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), T3: GA_3 (75 mg L^{-1}) + 8-HQ (200 mg L^{-1}) + Sucrose (1%), T4: GA_3 (75 mg L^{-1}) + $CaCl_2$ (5 g L^{-1}) + Sucrose (1%)

Correlation Analysis

Pearson correlation analysis showed that there were strong positive correlations between vase life and total solution uptake and positive correlations between vase life and stem firmness. In addition, strong negative correlations were found between vase life and bacterial growth and vase life FOR. Strong negative correlations were found between bacterial growth and stem firmness (Figure 5).

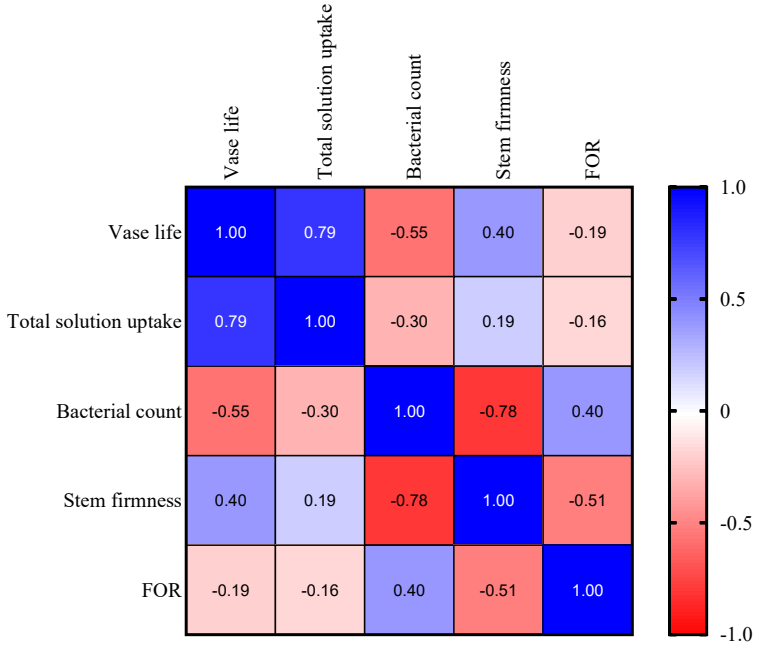

Figure 5. Correlation analysis between the studied parameters of different solutions. In the analysis, correlation was calculated using Pearson's method. Correlation values are visualised in dark red for low values and dark blue for high values.

DISCUSSION

Fresh cut flowers play a vital role in enhancing the quality of life and improving living standards. (Raza et al., 2018). After being separated from the parent plant, fresh cut flowers remain metabolically active and continue to absorb nutrients. However, the depletion of essential nutrients such as carbohydrates and inorganic salts inhibits their ability to sustain normal physiological functions (Noman et al., 2017). Various factors, such as impaired water absorption by the flower stem, dry petals, wilting, water loss, and a reduction in fresh weight, contribute to the decline in flower quality (Noman et al., 2018) A dull hue, along with bacterial and fungal infestations at the cut ends of flower stems, accelerates the aging of cut flowers. Vascular system blockage remains one of the most significant challenges in the post-harvest physiology of cut flowers.

When determining the vase life of cut flowers, flower opening rates is considered an important parameter that affects the freshness of the flower. The reason why measuring bud diameter is an effective way to determine the bloom rate is that the size of the bud directly affects the opening process and speed of the flower. Larger buds are usually more immature and therefore can have a longer flowering period. This contributes to the longer vase life of the flower. The bud diameter is also

related to the water and nutrient uptake capacity of the flower, with larger buds being able to take up these substances more efficiently, so that the flower stays fresh longer. Therefore, bud diameter measurements provide a reliable indicator for predicting the bloom rate and thus vase life. Flower opening rates in cut flowers are crucial for determining their aesthetic appeal and commercial value. Managing this process throughout the vase life is essential for maintaining flower quality. Controlling flower opening rates is considered a strategic approach in the cut flower industry, as it enhances visual appeal and increases the physiological durability of flowers. In this study, flower opening rates varied across treatments during the first three days and the subsequent three days of vase life. Combinations containing paclobutrazol demonstrated stable flower opening rates throughout the vase life, whereas combinations with gibberellic acid showed no statistically significant difference from the control. Paclobutrazol (PBZ), a highly effective plant growth regulator, was found to prolong vase life by reducing the rate of flower opening in cut flowers (Mansuroğlu et al., 2009). The rate of flower opening is less than in other applications; It may be because it delays flower opening and slows wilting by suppressing ethylene synthesis. In addition, PBZs regulate plant metabolism and control flowering processes by inhibiting gibberellin production (Bashir et al., 2017). At the same time, it contributes to keeping the flowers alive by maintaining cellular water balance (Desta and Amare, 2021). The increasing effect of PBZ on antioxidant enzymes may be due to the strengthening of the durability of flowers by combating oxidative stress (Saleem et al., 2024). On the contrary, GA_3 can improve the aesthetic appearance of cut flowers by accelerating flower opening in the vase life of cut flowers, but at high concentrations, it can reduce vase life and adversely affect vase life. Uniform flower opening and balance may not be achieved with concentrations that vary between plant species (Li et al., 2021; Taiz et al., 2015; van Doorn and Woltering, 2008; Halevy and Mayak, 1979).

Measuring colour senescence in cut flowers is important because it directly relates to flower quality and marketability. As flowers age, their color changes due to the degradation of pigments, which signals the onset of senescence. Flowers with vibrant, fresh colors are perceived as higher quality, and their visual appeal is a key factor in consumer purchasing decisions. Monitoring color senescence helps growers and suppliers identify the optimal time for harvesting and delivering flowers, ensuring they reach the market in their prime condition. This can enhance marketability by improving the aesthetic appeal and extending the flowers' shelf life, ultimately reducing waste and increasing sales (van Doorn and Broekhuysen, 2012). The *hue* ($h°$) angle and C^* value of red coloured cut roses during the vase life are related to the aging of the flower and the chemical changes of the pigments. In Control, T3 and T4 treatments, the $h°$ angle decreased over time, while it increased in T1 and T2 treatments. The increase in $h°$ angle causes the red colour to fade and become purplish brown, while the decrease causes it to decrease towards more orange or yellow colours. While C^* value expresses colour saturation, the lowest change in C^* value was observed in T2 and T1 treatments. The high C^* and $h°$ angle change angles may be due to the transformation of anthocyanins into different forms over time, acidity values of pH in vase solutions, oxidation of pigments (van Doorn and Kamdee, 2014; Ferrante et al., 2004; Hendry and Houghton, 1996). It has been reported that paclobutrazol increases the stability of pigments in plants, maintains the hue value in flowers and increases the colour saturation (C^*), and in our study, it is thought that it slows down the degradation of pigments such as anthocyanins and carotenoids, and the use of paclobutrazol in cut flowers contributes to the preservation of colour throughout the vase life of flowers and reduces oxidation and pigment loss with this effect (Desta and Amare, 2021; Mansuroğlu et al., 2009; Kamoutsis et al., 1999). As a growth regulator, Paclobutrazol may affects preventing discoloration. It has been determined in some cut flowers that pigments become more resistant to oxidation and dense pigment storage provide longer-term stability in both hue and C^* values (Desta and Amare, 2021; Kamoutsis et al., 1999)

Relative fresh weight one of the most significant physiological issues affecting decorative flowers after harvest is weight loss, which affects the quality and vase life. Maintaining the relative fresh weight of cut flowers is important for economic values in order to prolong their vase life (Saeed et al., 2016). According to our findings, treatment T2 had the highest floral FW and the control treatment (distilled water) had the lowest flower FW (Figure 2). Higher floral FW is generally seen as favorable since it may lead to longer vase life than those with fewer flowers (Soad et al., 2011). Paclobutrazol with 8-HQ and 1% sucrose treatment reduced the flower weight loss the most, followed by GA_3 with 8-HQ and 1% sucrose. This may be due to the effect of 8-HQ and sucrose in delaying petal aging and flower wilting (Kazaz et al., 2019; Mayak et al., 1974). Another significant element influencing the durability of commercial cut flowers is solution uptake (van Doorn, 2012). Following cut flower harvesting, water deficit and petal withering result from a disruption of the water balance caused by water intake and loss rates (Lü et al., 2010). Our findings demonstrated that, in comparison to the control, the vase solution containing paclobutrazol considerably maintained the water balance (Table 3).The results of our investigation were consistent with those of earlier research on ornamental cut flowers, which demonstrated that adequate water intake is crucial for preserving a desirable water balance and extending the vase life of ornamental cut flowers (Kumar, et al., 2018; Halevy and Mayak, 1979). In our study, the highest vase life among the different vase solution combinations was determined in cut flowers containing paclobutrazol + 8 HQ + sucrose solution. Changes in pH and electrical conductivity (EC) of the solution significantly impact the health and longevity of cut flowers. pH levels outside the ideal range (4.5-5.5) can hinder water and nutrient absorption, leading to wilting. Likewise, imbalanced EC, whether too high or too low, can cause osmotic stress or nutrient deficiencies, affecting water uptake and flower development. Maintaining proper pH and EC ensures optimal conditions for flower longevity (Tayeh and Shafiee, 2015; Bugas and Smith, 2002).

In our study, the highest vase life among the different vase solution combinations was determined in cut rose flowers containing paclobutrazol + 8HQ and sucrose solution. Paclobutrazol is a chemical substance belonging to a triazole group used in plants as a growth regulator. This compound inhibits the biosynthesis of giberellin in plants, slowing the growth rate and providing plants with a compact, durable structure. The reason for the effect of the use of paclobutrazol on the vase life of cut flowers may be related to its ability to control water loss and metabolic activities of the plant. Paclobutrazol reduces

water loss by closing the stomata and allows the plant to use water more efficiently and effective in water stress (Davari et al., 2022; Mohan et al., 2020; Iqbal et al., 2006). By suppressing the synthesis of giberellin, it slows down metabolic activities, thus delaying the ageing process and prolonging the vase life of flowers. Reduced water uptake may have increased the vase life of flowers by helping to maintain the freshness of flowers by enabling more efficient use of water and nutrients (Kumar et al., 2018). 8-HQ has also been shown to increase the water intake of flowers by reducing bacterial interactions and increasing the vase life of flowers by maintaining fresh flower weight. In parallel with our study, Paclobutrazol treatment was reported to delay wilting and leaf yellowing in cut roses by prolonging the vase life of cut roses, and this effect was attributed to the reduction of water loss and ethylene production (Halevy and Mayak, 1979). A study on cut lily flowers revealed that paclobutrazol application significantly prolonged vase life while enhancing and stabilizing water uptake (Singh et al., 2008).

The superior performance of the T2 treatment compared to the others can be attributed to the synergistic effect of Paclobutrazol and 8-Hydroxyquinoline (8-HQ). Paclobutrazol inhibits gibberellin biosynthesis, slowing plant growth, reducing respiration rates, and optimizing flower metabolism by minimizing energy loss (Rogers, 2012). Meanwhile, 8-HQ prevents microbial colony formation in the vase water and blockage of conductive tissues, facilitating more efficient water uptake by the flower (Van Doorn, 1997). This combination enhances the resistance of floral tissues to both physiological and microbial stresses. In contrast, T3 and T4 treatments, which included GA_3, stimulated plant growth and increased metabolic rates, leading to rapid energy depletion, water loss, and accelerated senescence in cut flowers (van Doorn and Reid, 1995). Although $CaCl_2$ in T1 and T4 treatments improved floral durability by strengthening the cell walls, it was less effective than 8-HQ in suppressing microbial growth (Halevy and Mayak, 1979). Additionally, sucrose, present in all treatments, was utilized more efficiently in T2 due to the metabolic slowing effect of Paclobutrazol. The low microbial growth in T2 also allowed sucrose to function effectively without degradation. Thus, the T2 treatment outperformed the others by combining the anti-senescence properties of Paclobutrazol with the microbial control capabilities of 8-HQ. The partial stem firmness in the T2 treatment can be attributed to the combined effects of Paclobutrazol and 8-Hydroxyquinoline (8-HQ). Paclobutrazol slows growth by inhibiting gibberellin biosynthesis, reducing metabolic activity and water loss, which helps maintain structural integrity and delays tissue senescence (Rogers, 2012) 8-HQ prevents microbial colonization and blockage of vascular tissues, ensuring efficient water uptake and minimizing stress on stem tissues (Van Doorn, 1997). In contrast, GA_3 in T3 and T4 increased metabolic rates and water loss, leading to faster deterioration of stem tissues (van Doorn and Reid, 1995), while $CaCl_2$ in T1 and T4 improved cell wall strength but lacked sufficient microbial control, maybe resulting in reduced overall stem durability (Halevy and Mayak, 1979).

CONCLUSION

This study showed that the use of Paclobutrazol + 8HQ + Sugar (T2) significantly extended the vase life of cut roses to 13.92 days compared to the control (9.67 days). Additionally, this treatment allowed buds to open later during the first few days and reduced bacterial growth, while maintaining total solution uptake at 36.38 ml (higher than the control at 25.48 ml). This treatment also effectively delayed the decline in petal color maintenance, which in turn postponed flower senescence. In comparison, other treatments such as T1, T3, and T4 exhibited similar vase lives (9.75-10.0 days) and solution uptakes (ranging from 23.85 ml to 29.06 ml), but did not show the same level of improvement in vase life and aesthetic value as the Paclobutrazol + 8HQ + Sugar combination. Overall, this study demonstrates the positive effects of plant growth regulators on vase life and flower preservation, providing a solid theoretical basis for the application of Paclobutrazol + 8HQ + Sugar. Testing different doses of this combination offers an innovative approach to developing new preservatives, which is crucial for the development of effective preservatives not only for roses but for all cut flowers.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Declaration of Interests

The authors have no conflict of interest to declare.

Author contribution

The contribution of the authors to the present study is equal. All the authors read and approved the final manuscript.
All the authors verify that the text, figures, and tables are original and that they have not been published before.

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