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Prolong the vase life and improve quality of (*gladiolus hybrid* cv. White prosperity) cut flower by using some growth regulators

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إطالة عمر و تحسين جودة أزهار الجلاديولاس المقطوفة صنف وايت بروسبيرتى باستخدام بعض منظمات النمو

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الملخص:

أجريت هذه الدراسة لتقييم أداء ما بعد الحصاد لشماريخ أزهار الجلاديولاس المقطوفة (*Gladiolus hybrid* cv. White Prosperity) المعاملة بتركيزات مختلفة من حمض الجبريليك (GA3) و6-بنزيل أمينو بيورين (BA-6) بشكل منفرد أو في توليفة مركبة خلال موسمي 2024 و2025. اختُبرت سبعة محاليل حفظ تشمل: الماء المقطر (كمعاملة مقارنة/كنترول)، حمض الجبريليك بتركيزي 25 و50 ملجم/لتر، و6-بنزيل أمينو بيورين بتركيزي 15 و30 ملجم/لتر، بالإضافة إلى توليفتين مركبتين هما: (25 ملجم/لتر حمض جبريليك + 15 ملجم/لتر 6-بنزيل أمينو بيورين)، و(50 ملجم/لتر حمض جبريليك + 30 ملجم/لتر 6-بنزيل أمينو بيورين). أُضيف إلى جميع محاليل الحفظ 200 ملجم/لتر من نترات الفضة (AgNO3) و1.5% سكروز. خلال التجربه تم قياس الوزن الطازج للأزهار والنباتات، وعمر المحلول (مدة بقاء الأزهار في الإناء)، ومحتوى الكلوروفيل الكلي بوحدة (SPAD) ، والكربوهيدرات الكلية، والسكريات الكلية، ومحتوى البروتين، والعلاقات المائية (الامتصاص والفقد والتوازن)، وأعداد البكتيريا في محلول الحفظ. وأظهرت النتائج أن المعاملة المركبة (50 ملجم/لتر حمض جبريليك + 30 ملجم/لتر 6-بنزيل أمينو بيورين) كانت الأفضل في جميع الصفات المدروسة خلال كلا الموسمين؛ إذ أدت إلى زيادة عمر الأزهار في الإناء بنسبة تراوحت بين 63.71% و66.67% مقارنة بمعاملة المقارنة (الكنترول)، وسجلت أعلى احتفاظ بالوزن الطازج، وأقصى محتوى من الكلوروفيل (38.14 و40.18 وحدة SPAD)، وأعلى محتوى للكربوهيدرات الكلية (20.27% و22.32%)، والسكريات الكلية (4.22% و4.59%)، والبروتين (12.83% و13.64%). كما حققت هذه المعاملة أعلى معدل لامتصاص الماء (59.33 و63.30 جم/زهرة) وتوازناً مائياً ممتازاً، بالتزامن مع تسجيل أقل أعداد للبكتيريا في محلول الحفظ (36.42×10^2 و64.89×10^2 وحدة تشكيل مستعمرة/مل) خلال موسمي 2024 و2025 على التوالي. أظهر عمر الأزهار في الإناء ارتباطاً إيجابياً قوياً مع المتغيرات الفسيولوجية الهامة مثل الاحتفاظ بالكلوروفيل، ومستويات الكربوهيدرات والبروتين، وامتصاص الماء، بينما ارتبط سلبياً مع فقد الماء والانتشار البكتيري. وتؤكد النتائج أن محاليل الحفظ المحتوية على حمض الجبريليك (GA3) و6-بنزيل أمينو بيورين (BA-6) تعمل بشكل تآزري على تأخير الشيخوخة، والحفاظ على السلامة الفسيولوجية، وإطالة العمر التسويقي لشماريخ أزهار الجلاديولاس المقطوفة صنف "White Prosperity".

الكلمات الدالة: بنزيل أمينو بيورين ، حمض الجبريليك، ما بعد الحصاد، زهرة الجلاديولس

Abstract

The present study was conducted to investigate the postharvest performance of gladiolus (*Gladiolus hybrid* cv. White Prosperity) cut spikes treated with different concentrations of gibberellic acid (GA3) and 6-benzylaminopurine (6-BA) individually and in combination during 2024 and 2025 seasons Seven holding solutions were tested: distilled water (control), GA3 at 25 and 50 mg/L, 6-BA at 15 and 30 mg/L, and two combinations (25 mg/L GA3 + 15 mg/L 6-BA; 50 mg/L GA3 + 30 mg/L 6-BA). All solutions were supplemented with 200 mg/L AgNO3 and 1.5% sucrose. The parameters determined were fresh weight of flowers and plants, vase life, total chlorophyll content (SPAD units), total carbohydrates, total sugars, protein content, water relations (uptake, loss and balance) and bacterial counts in the vase solution. The results showed that the combined application of 50 mg/L GA3 + 30 mg/L 6-BA was the best for all traits measured in both seasons. This treatment also improved the vase life by 63.71-66.67% over control, recorded highest fresh weight retention, maximum chlorophyll content (38.14 and 40.18 SPAD units), maximum total carbohydrates (20.27 and 22.32%), total sugars (4.22 and 4.59%) and protein content (12.83 and 13.64%), maximum water uptake (59.33 and 63.30 g/flower) and most favorable water balance along with lowest bacterial counts (36.42 and 64.89 $x10^2$ CFU/ml) during 2024 and 2025, respectively. Vase life showed strong positive correlations with important physiological parameters such as chlorophyll retention, carbohydrate and protein status, and water uptake, but negative correlations with water loss and bacterial proliferation. The results confirm that GA3 and 6-BA containing postharvest holding solutions act synergistically in delaying senescence, maintaining physiological integrity and prolonging the marketable life of gladiolus cv. White Prosperity cut spikes.

Keywords: Benzyladenine, Gibberellic acid, post-harvest and gladiolus flower.

Introduction

Gladiolus (*Gladiolus hybrid* cv. White Prosperity), a member of the Iridaceae family, is a beautiful flower that is sometimes referred to as a "sword lily" because of the form of its leaves (**Mishra and Khanal, 2019**). Furthermore, the gladiolus, sometimes referred to as the queen of bulbous flowers, is a flower of perfection and elegance due to its flower spikes with enormous florets that are attractively shaped, have vivid colors, vary in size, and have an exceptional shelf life (**Kumar *et al.* 2020**). Gladiolus is a prominent commercial crop, holding a unique status as a cut flower both in domestic markets and global exports. It ranks among the top ten commercial flowers worldwide, occupying the foremost position in terms of economic significance and production volume due to its potential for year-round cultivation (**Al-Hasnawi *et al.* 2019**). Notwithstanding its aesthetic and economic significance, gladiolus spikes, including the renowned white-flowered cultivar 'White Prosperity,' experience a limited postharvest lifespan, as individual florets typically endure merely a few days post-harvest, generally lasting around four days, thereby necessitating ongoing endeavors to prolong the vase life of this vital cut flower. The brief lifespan, coupled with gradual floret abscission, stem curvature, and diminished turgidity, significantly restricts the marketability and visual appeal of the spikes throughout transportation, storage, and retail presentation (**Soliman, 2025**).

The international flower trade necessitates that cut flowers preserve their postharvest quality for an extended duration, both along the market chain and at the consumer level (**Wu *et al.*, 2025**). Nonetheless, certain postharvest challenges have been seen in gladiolus, such as inadequate water absorption and uptake, alteration in floret color and quick darkening, abscission, and early senescence (**Singh *et al.*, 2019; Rani *et al.*, 2024**). Due to the rising production value of cut flowers, it is crucial to maintain excellent post-harvest quality of the harvested blooms. The brief vase life of cut flowers is associated with wilting, ethylene generation (which accelerates senescence in several flowers), and vascular constriction due to air embolism and microorganisms (**Sun *et al.*, 2021; Wu *et al.*, 2025**). These variables inhibit continuous water absorption and transpiration in the leaves of cut flowers, resulting in a general water deficit in the floral and stem tissues (**Anderson, 2023**), hence diminishing the vase life of cut flowers. Recent studies have established that water stress, microbial activity, carbohydrate depletion, and ethylene exposure are the principal physiological factors constraining the vase life of gladiolus. The utilization of appropriate preservatives may prolong the floral spikes vase life, enhancing consumer pleasure and corporate profitability. Preservative treatments are often necessary to provide an energy source, inhibit microbial growth and vascular obstruction, enhance water absorption in the stem, and mitigate the detrimental effects of ethylene (**Chen, 2024; Wu *et al.*, 2025**). Consequently, a vase solution with germicides, sugar, and an ethylene inhibitor would extend the vase life. Sucrose provides essential substrates for respiration and prolongs vase life, allowing cut flowers harvested at the bud stage to flourish (**Rani *et al*., 2024**). $AgNO_3$ is a potent antibacterial agent and ethylene inhibitor (**Mwelase *et al.*, 2024; Wu *et al.*, 2025**). Hormones regulate all developmental and senescence processes in cut flowers. The application of plant growth regulators has enabled the regulation of floral characteristics and blossoming timing in several cut flowers to meet market demands (**Cunha Neto *et al.*, 2023**). Utilizing growth regulators for plants has become integral to the cultural practices of several ornamental plants, including gladiolus, for the manipulation of vegetative and floral traits both in the field and under postharvest conditions. It facilitates the regulation of physiological processes in plants, even when employed at minimal concentrations. Preservative therapies, such as sucrose, salicylic acid, and gibberellic acid, have significant ability to extend longevity by as much as 10 days (**Rani *et al.*, 2024; Sarje *et al.*, 2024**).

Additionally, endogenous hormones have a vital role in regulating physiological processes significantly, which enhances quantitative blooming and prolongs the vase life of cut flowers (**Singh *et al.*, 2017**). Gibberellins and cytokinins are examples of plant growth regulators that have been demonstrated in multiple studies to extend the postharvest vase life of certain cut flowers. The utilize of growth regulators, specifically gibberellic acid (GA_3) and kinetin (kin), as pulsing solutions has been shown to extend bloom longevity (**Abd El-Kafie *et al.*, 2016**). GA_3 enhances membrane integrity, postpones senescence (**Huang *et al.*, 2026**), increases carbohydrate content, and improves water retention in cut flowers, so extending their lifespan for commercial purposes. **Singh *et al.* (2019**) found that the maximum spike length on the 6th and 9th days in a vase was associated with the pre-soaking treatment of cut corms in GA_3 at 50 ppm. The highest water absorption by gladiolus spikes occurred with GA_3 100 after three days.

Cytokinins significantly influence nearly all biological processes in plant growth, including defense mechanisms, abscission, floral organ maturity, and leaf/flower senescence, as well as reactions to different biotic and abiotic stimuli **(Bengoa Luoni *et al.*, 2019**). Prior research demonstrated the advantages of these phytohormones for molecular and physiological functions, as well as their function in protecting against biotrophic diseases. Cytokinins are now recognized for regulating the transport and metabolism of carbohydrates and amino acids essential for plant development, alongside various macronutrients such as nitrogen, sulfur, phosphorus, and iron (**Albrecht and Argueso, 2017**). 6-benzylaminopurine (BAP) is recognized as an effective growth regulator; it enhances resilience by inhibiting free radicals in response to water stress or abiotic factors (**Kamran *et al.*, 2021**) and by inducing resistance in the perennial roots of Lolium perenne L. cv. Pinnacle (**Ma *et al.*, 2016**). Foliar senescence is frequently delayed by the exogenous application of 6-BAP. The external application of cytokinin to trimmed and pruned flowers was observed to delay leaf chlorosis and decrease ethylene production (**Iqbal *et al*., 2017**). **Kapri *et al.* (2018**) demonstrated that the administration of a single dosage of GA3 (200 ppm) produced the highest flower buds number / plant and induced early flowering, whereas plants subjected with a BA (100 ppm) single dose exhibited the shortest duration until the color display of the first and third lily flower buds. The use of GA3 at 100 ppm, administered in single and double doses, respectively, resulted in the greatest diameter and length of the pedicle. The vase life of cut lilies was improved by the application of a single dosage of BA at 100 ppm. Moreover, **Huang *et al.* (2026)** recently revealed that the vase solution treatments including 6-BA and GA3 considerably prolonged vase life, improved antioxidant capability, decreased MDA formation, and postponed chlorophyll degradation. The largest significant impact was noted with 30 mg·L−1 6-BA, which prolonged vase life to 25.33 days—a 14.26% enhancement relative to the control—while sustaining elevated peroxidase (POD) activity and augmenting chlorophyll content.

This study aimed to assess the effectiveness of exogenous applications of gibberellic acid (GA_3) and benzyladenine (BA) as environmentally sustainable postharvest treatments for enhancing both pre-harvest flowering attributes and postharvest longevity of gladiolus (*Gladiolus hybrida*) cut flowers. Specifically, this study seeks to: 1) Evaluate the effects of GA_3 and BA pulsing solutions on flowering parameters, 2) Assess the impact on postharvest quality indices (vase life, water uptake capacity, and floret opening percentage, 3) Determine the optimal concentration and treatment protocol for maximizing commercial viability while minimizing environmental impact, and 4) These findings will contribute to the development of phyto-hormone-based postharvest strategies that align with sustainable agriculture practices in the global cut flower industry

MATERIAL AND METHODS

Plant material was acquired from a commercial nursery specializing in flowers and ornamental plants in Benghazi. Uniform flower spikes measuring 80 cm in length, featuring 3-4 leaves and approximately 15 flower buds per spike, were harvested in the early morning during the successful seasons of 2024 and 2025 in April. This was conducted to examine the effects of varying concentrations of 6-benzylaminopurine and GA3, both individually and in combination, on vase life, microbial growth in the vase solution, and certain chemical analyses of cut gladiolus spikes at the Agriculture Research Center.

The spikes were pre-cooled in cold water for 30 minutes to eliminate field heat. Subsequently, the flower was re-cut 5 cm from the stem's end, the lower third of the stems was excised, and their weights were recorded along with their original fresh weights.

In the experiment, clean glass bottles served as containers for the holding solution, which was prepared using tap water and remained unchanged throughout the duration of the experiment. Each 2 spikes were individually positioned in a 100 ml graduated cylinder containing preservative solutions to terminate vase life at temperatures between 17-20 ◦C and relative humidity of 50-56%, along with continuous illumination from fluorescent lamps at 1000 Lux for 24 hours.

The current study was conducted as a factorial experiment utilizing a completely randomized design. Each treatment consisted of three replicates for each spike. Each treatment from the seven holding solutions was conducted in an experiment comprising 200 mg L-1 silver nitrate and 1.5% sucrose. The study encompasses seven treatments, which can be elucidated under the following factors:

1. Control: distilled water.
2. Gibberellin (GA3) at 25 mg L^{-1}.
3. Gibberellin (GA3) at 50 mg L^{-1}.
4. 6-benzylamino purine (6-BAP) at 15 mg L^{-1}.
5. 6-benzylamino purine (6-BAP) at 30 mg L^{-1}.

6. GA3 at 25 mg L^{-1} + 6-BAP at 15 mg L^{-1}.
7. GA3 at 50 mg L^{-1} + 6-BAP at 15 mg L^{-1}.

Data recorded:

- **Weight of flower g/flower** and **fresh weight g/plant** at the end of the experiment.
- **Vase life (day):** as mentioned by **Massoud *et al.* (2015**), the count of days during which 50% or more of the head flowers on a spike were considered unattractive.
- **Water relations:** (a) **water uptake (g/ flower**): Throughout the vase life assessment period, the mass of vases filled with aqueous solutions devoid of cut flowers was documented bi-daily. The total days of vase solution uptake rate were computed at the conclusion of the vase life period for each treatment using the following formula: Water uptake [g/flower/day] = [St1 - St]; where St represents the weight of the water solution (g) on days 2, 4, 6, etc., and St1 denotes the weight of the water solution (g) on the preceding day (0, 2, 4, 6, etc.) as per **Bazaz *et al*. (2015**). (b) Water loss (g/flower): Aggregate water loss (g/flower) Water loss was assessed during the evaluation period of vase life. The weights of the vases with cut flowers and vase solution were documented bi-daily. The total days of vase solution loss rate were computed at the conclusion of the vase evaluation period for each treatment as follows: Water loss (g/flower/day) = (Ct1 - Ct), where Ct represents the aggregate weight of cut flowers and vase solution (g) at days 2, 4, and 6, while Ct1 denotes the combined weights of cut flowers and vase solution (g) at days 0, 2, and 4, respectively, as per **Bazaz *et al*. (2015**). (c) Water balance (g/flower) = the disparity between water absorption and water evaporation
- **Chlorophyll content value (SPAD unit):** Measurements of chlorophyll levels were recorded on the seventh day of the shelf life period using a portable chlorophyll meter (SPAD-505 plus-China), as per **Yadava (1986)**
- **Total sugar (% D.W):** was documented on the seventh day of the shelf life duration. The total sugars of air-dried leaves were quantified following the methodology **of Sadasivam and Manickam (1996)**.
- **Total Carbohydrates and protein (% D.W**): were determined in the 7^{th} day during life period of the experiments according to the method described by **AOAC (2019)**
- **Bacterial counts averages (C.F.U/ml):** Biological assessments were conducted in the preservation solutions following a three-day incubation period. Each sample was processed by extracting 1 mL, which was then diluted stepwise with sterilized distilled water through six successive dilution levels. Subsequently, one milliliter from each of the fourth, fifth, and sixth dilution levels was transferred into Petri dishes containing nutrient agar medium. The medium consisted of the following components: 5 g peptone, 3 g beef extract, 5 g NaCl, 15 g agar, and 1000 mL distilled water, with the pH adjusted to 6.8–7.0. The colonies were counted after the cultures were cultured at 30°C for 72 hours following the methodology outlined by **Massoud *et al*. (2015).**

According to **Gomez and Gomez (1984**), analysis of variance (ANOVA) was used to examine all of the resulting data. The Costat software system was used to examine treatment means using Duncan's test and L.S.D. at 5%.

RESULTS

1. Weight of flower g/flower:

The effectiveness of gladiolus spikes for postharvest research was assessed and tracked for various GA3 and 6-BA concentrations at various intervals throughout the trials. In general, the administration of growth regulators dramatically changed all of the gladiolas' growth, cut flower, and vase life metrics.

Data concerning weight of the flower spikes noted after immersion in vase solution are presented in Table (1). Significant difference was observed for weight of flower spikes in various solution applications. However, weight of flower spikes per vase solution ranged from 20.33 to 29.12 g/flower. The highest values of weight flower recorded with holding solution contains 50 ppm GA3+30 mg/L 6-BA. The same trend was true during both seasons.

Table (1) Weight of flower g/flower as affected by various chemical solutions of preservatives during 2024 and 2025 seasons.

Treatments	Weight of flower g/flower	
	2024	2025
Control	20.33g	21.55g
25 mg/L GA3	23.12e	24.54e
50 mg/L GA3	26.46c	27.76c
15 mg/L 6-BA	21.98f	22.86f
30 mg/L 6-BA	24.63d	26.47d
25 mg/L GA3+15 mg/L 6-BA	27.51b	29.55b
50 mg/L GA3+30 mg/L 6-BA	29.12a	31.29a
LSD $_{at\ 5\%}$	0.53	0.43

2. Fresh weight g/plant:

The information displayed in Table (2) showed the effect of hold solution at different concentration from GA3 and 6-BA on fresh weight g/plant. A review of the results clearly indicates a significant change in plant weight after post-harvest due to the post-soaking treatment with varied concentrations of GA3 and 6-BA, whether administered singly or in combination. All holding solution increased fresh weight. So, the highest values of fresh weight g/plant significantly scored with the combination between GA3 at 50 mg/L + 6-BA at 30 mg/L which recorded 35.63 and 38.15 g/plant during 2024 and 2025. Irrespective control solution, the lowest values of this parameter were gained by solution at 30 mg/L 6-BA which recorded 33.38 and 35.49 g/plant during 2024 and 2025.

Table (2) Fresh weight g/plant as affected by various chemical solutions of preservatives during 2024 and 2025 seasons.

Treatments	Fresh weight g/plant	
	2024	2025
Control	32.14d	34.02f
25 mg/L GA3	33.38bcd	35.49e
50 mg/L GA3	35.55a	36.93c
15 mg/L 6-BA	32.72cd	37.40b
30 mg/L 6-BA	33.96abc	36.19d
25 mg/L GA3+15 mg/L 6-BA	35.01ab	37.47b
50 mg/L GA3+30 mg/L 6-BA	35.63a	38.15a
LSD $_{at\ 5\%}$	1.76	0.29

3. Vase life:

The impact of growth regulator different treatments on vase life is illustrated in Table (3) and Figure (1) cleared that high significant difference was observed among various vase solution for vase life recorded at 50% termination of the flower spikes. Data indicated that all employed components prolonged the inflorescence duration of gladiolus cut spikes in comparison to the control treatment. The GA3 treatment resulted in the longest vase life for gladiolus cut spikes. Furthermore, the combination of GA3 at 50 mg/L and 6-BA at 30 mg/L resulted in the longest length of inflorescence compared to the control group. The previous treatment resulted in a 63.71% and 66.67% enhancement of inflorescence vase life compared to the control.

Table (3): Inflorescence duration (vase-life) (day) as affected by various chemical solutions of preservatives during 2024 and 2025 seasons.

Treatments	Vase life days	
	2024	2025
Control	7.33e	9.00d
25 mg/L GA3	9.33cd	11.00c
50 mg/L GA3	10.67abc	13.33b
15 mg/L 6-BA	8.00de	10.33cd
30 mg/L 6-BA	10.00bc	12.67b
25 mg/L GA3+15 mg/L 6-BA	11.33ab	13.67ab
50 mg/L GA3+30 mg/L 6-BA	12.00a	15.00a
LSD $_{at\ 5\%}$	1.50	1.49

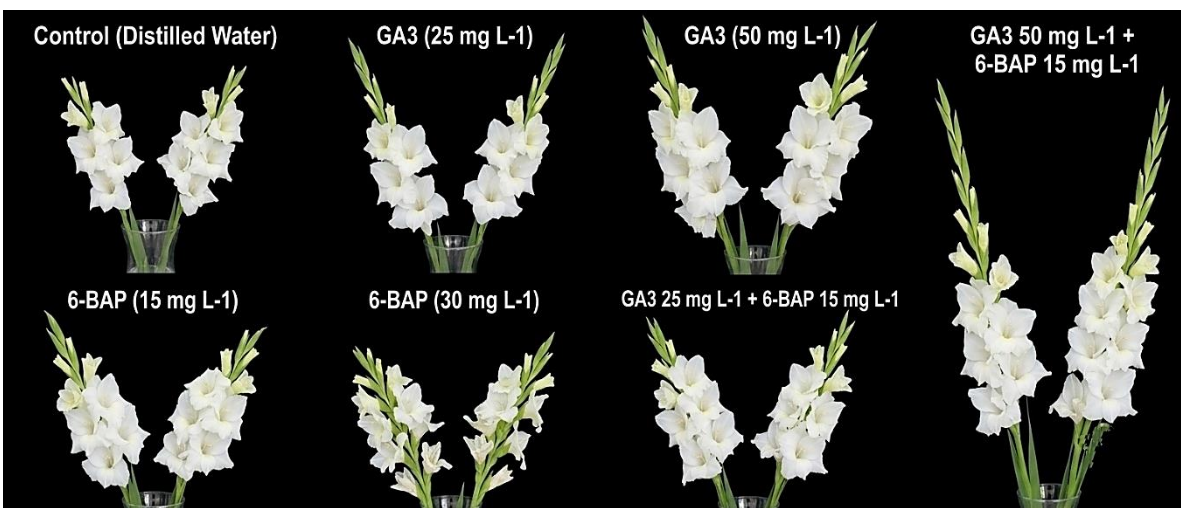

Fig (1): Comparison of Gladiolus hybrida cv. White Prosperity cut flowers morphology under the studied different treatments

4. Chlorophyll content value (SPAD units):

Table (4) illustrates that the chlorophyll content of the gladiolus spike leaves diminished by the conclusion of the experiment in comparison to the first measurements. The reductions were likely attributable to the natural degradation of leaf pigments following the severance of the spikes. All treatments significantly increased the chlorophyll content value comparing the control. Besides, found that adding both GA3 and 6-BA increased the chlorophyll value, on the other words, the optimal holding solution that sustained the highest mean total chlorophyll values across both seasons was the combination treatment of GA3 at 50 mg/L and 6-BA at 30 mg/L, in contrast to the control treatment (distilled water), which exhibited the lowest mean chlorophyll values.

Table (4): Chlorophyll content value (SPAD units) as affected by various chemical solutions of preservatives during 2024 and 2025 seasons.

Treatments	Chlorophyll SPAD	
	2024	2025
Control	27.13g	25.32g
25 mg/L GA3	30.53e	30.86e
50 mg/L GA3	34.42c	36.02c
15 mg/L 6-BA	28.98f	27.81f
30 mg/L 6-BA	32.38d	33.39d
25 mg/L GA3+15 mg/L 6-BA	36.11b	37.97b
50 mg/L GA3+30 mg/L 6-BA	38.14a	40.18a
LSD $_{at\ 5\%}$	0.66	0.87

5. Total carbohydrates content (%):

According to this study the total carbohydrates content (%) in gladiolus increased significantly due to the growth regulators in holding solution at different concentration whether individually or mixed together. Generally, data of the carbohydrates content (%) mean values at Table (5) indicated that the application of GA3 or 6-BA elevated the total carbohydrate content (%) in gladiolus cut spikes compared to the control group. The greatest mean values were observed with the administration of 50 mg/L GA3 and 30 mg/L 6-BA, yielding scores of 20.27% and 22.32% in 2014 and 2025, respectively. While the lowest mean values recorded with treatment 15 mg/L 6-BA which scored 14.65 and 15.94% in 2024 and 2025, respectively away from the control.

Table (5): Total carbohydrates content (%) as affected by various chemical solutions of preservatives during 2024 and 2025 seasons.

Treatments	Carbohydrates %	
	2024	2025
Control	13.33g	14.71g
25 mg/L GA3	15.86e	17.09e
50 mg/L GA3	18.16c	19.92c
15 mg/L 6-BA	14.65f	15.94f
30 mg/L 6-BA	16.95d	18.56d
25 mg/L GA3+15 mg/L 6-BA	19.16b	20.98b
50 mg/L GA3+30 mg/L 6-BA	20.27a	22.32a
LSD $_{at\ 5\%}$	0.19	0.48

6. Total sugar content (%):

Data presented in Table (6), revealed that all studied holding solution at different concentration of GA3 and 6-BA treatments significantly increased total sugar of gladiolus when compared to the control treatment during 2024 and 2025.

The content of total sugar of gladiolus was increased with increasing concentration of GA3 and 6-BA, thus the highest mean values was scored by 50 mg/L GA3 individually, while the combination between GA3 and 6-BA recorded the maximum mean values of total sugar% which scored 4.22 and 4.59% during 2024 and 2025, respectively in holding solution contains 50 mg/L GA3+30 mg/L 6-BA. While the lowest values recorded with control treatment.

Table (6): Total sugar content (%) as affected by various chemical solutions of preservatives during 2024 and 2025 seasons.

Treatments	Total sugar%	
	2024	2025
Control	2.06g	2.31g
25 mg/L GA3	2.84e	2.91e
50 mg/L GA3	3.54c	3.82c
15 mg/L 6-BA	2.40f	2.58f
30 mg/L 6-BA	3.15d	3.30d
25 mg/L GA3+15 mg/L 6-BA	3.86b	4.23b
50 mg/L GA3+30 mg/L 6-BA	4.22a	4.59a
LSD $_{\text{at 5\%}}$	0.18	0.04

7. Protein content (%):

In this study, both 6-BA and GA3 application affected the protein content as indicated in Table (7). Addition of GA3 and 6-BA significantly raised protein content in gladiolus in comparison with control treatment. Treatment with 50 mg/L GA3 + 30 mg/L 6-BA, was the most effective one in raising protein content which recorded 12.83 and 13.64% during the 2024 and 2025 seasons, respectively. Irrespective control solution, the lowest values of this parameter were gained by solution at 15 mg/L 6-BA which scored 10.06 and 11.01% during 2024 and 2025, respectively.

Table (7): Protein content (%) as affected by various chemical solutions of preservatives during 2024 and 2025 seasons.

Treatments	Protein%	
	2024	2025
Control	9.45g	10.38g
25 mg/L GA3	10.66e	11.43e
50 mg/L GA3	11.85c	12.64c
15 mg/L 6-BA	10.06f	11.01f
30 mg/L 6-BA	11.23d	11.94d
25 mg/L GA3+15 mg/L 6-BA	12.26b	13.05b
50 mg/L GA3+30 mg/L 6-BA	12.83a	13.64a
LSD $_{\text{at 5\%}}$	0.13	0.24

7. Water relations:

The data displayed in Table (8) indicated that at the conclusion of the experiment, the maximum water uptake (59.33 and 63.30 g/flower) during both seasons 2024 and 2025, respectively were recorded when combination of both 50 mg/L GA3+30 mg/L 6-BA. Furthermore, this combination consistently yielded greater water uptake throughout the experiment compared to the majority of other combinations from the onset of the shelf life period.

The data in the table indicate that the control treatment (distilled water) resulted in the highest water loss (g/flower) in gladiolus cut spikes, thereby demonstrating a negative effect on water retention during the experiment. This indicates that GA3 predominated in the majority of combinations compared to the cytokinin treatment. The most favorable combinations for reduced water loss were observed with the interaction of 50 mg/L GA3 and 30 mg/L 6-BA.

According to the results shown in Table (8), it was observed that the greatest water balance for the majority of the interaction treatments was recorded from the commencement to the conclusion of the vase life. Furthermore, the combinations of 50 mg/L GA3 and 30 mg/L 6-BA were superior in that regard. Conversely, the lowest water balance values were seen from the commencement to the conclusion of the experiment, namely during the interactions of the control (distilled water) followed by 15 mg/L 6-BA.

Table (8): Water relations as affected by various chemical solutions of preservatives during 2024 and 2025 seasons.

Treatments	Water balance					
	Water uptake g/flower		Water loss g/flower		Water balance g/flower	
	2024	2025	2024	2025	2024	2025
Control	31.76g	35.50g	54.13a	52.21a	-22.37g	-16.72g
25 mg/L GA3	41.14e	44.70e	45.81c	44.07c	-4.67e	0.62e
50 mg/L GA3	51.14c	54.87c	36.49e	34.44e	14.65c	20.44c
15 mg/L 6-BA	36.09f	40.73f	49.80b	48.04b	-13.71f	-7.31f
30 mg/L 6-BA	45.83d	49.34d	40.80d	39.00d	5.03d	10.34d
25 mg/L GA3+15 mg/L 6-BA	54.66b	58.49b	32.76f	31.00f	21.90b	27.48b
50 mg/L GA3+30 mg/L 6-BA	59.33a	63.30a	27.77g	26.45g	31.56a	36.86a
$LSD_{\text{at 5\%}}$	2.92	0.99	2.78	0.31	2.39	1.05

8. Bacterial counts:

The results in Table (9) indicate that the incorporation of growth regulators into the holding solution considerably reduced the bacterial counts of gladiolus cut spikes compared to the control treatment. The minimum average of bacterial count 36.42×10^2 and 64.89×10^2 C.F.U/ml) during 2024 and 2025, respectively was obtained by using treatment of 50 mg/L GA3+30 mg/L 6-BA. Conversely, the maximum average (216.59×10^2 and 326.42×10^2 C.F.U/ml) of bacterial count during 2024 and 2025, respectively was recorded for the control (distilled water) followed by (185.95×10^2 and 277.27×10^2 C.F.U/ml) during 2024 and 2025, respectively scored with 15 mg/L 6-BA.

Table (9): Bacteria count of gladiolus as affected by various chemical solutions of preservatives during 2024 and 2025 seasons.

Treatments	Count bacterial $X10^3$ cfu ml	
	2024	2025
Control	216.59a	326.42a
25 mg/L GA3	153.88c	244.63c
50 mg/L GA3	97.20e	171.46e
15 mg/L 6-BA	185.95b	277.27b
30 mg/L 6-BA	127.10d	201.37d

25 mg/L GA3+15 mg/L 6-BA	56.48f	108.35f
50 mg/L GA3+30 mg/L 6-BA	36.42f	64.89g
LSD $_{at\ 5\%}$	20.47	1.67

9. Corelationship between vase longevity and physiological metrics:

To clarify the relationships among the studied traits, Pearson correlation coefficients were calculated from the treatment mean values recorded during the 2024 and 2025 seasons (n = 14) and are presented as a correlation matrix in Fig. (2), where circle size and color intensity indicate the strength and direction of each coefficient (r). Vase life was very strongly and positively correlated with protein content (r = 0.96), total carbohydrates (r = 0.96), water uptake (r = 0.92), water balance (r = 0.90), total sugars (r = 0.90) and total chlorophyll content (r = 0.86), whereas it was strongly and negatively correlated with water loss (r = -0.88) and, to a markedly lesser extent, with bacterial counts in the vase solution (r = -0.49). The remaining physiological and biochemical traits were themselves highly inter-correlated, particularly the water-relations parameters together with chlorophyll, carbohydrate, sugar and protein contents (r ≥ 0.94 in most cases), while bacterial counts consistently showed the weakest, although still negative, association with the other quality indicators. These results confirm that the prolongation of vase life achieved with GA3 and 6-BA treatments was closely and simultaneously linked to the maintenance of pigment, carbohydrate and protein status together with a more favorable water balance, with suppression of bacterial proliferation playing a comparatively smaller, supportive role.

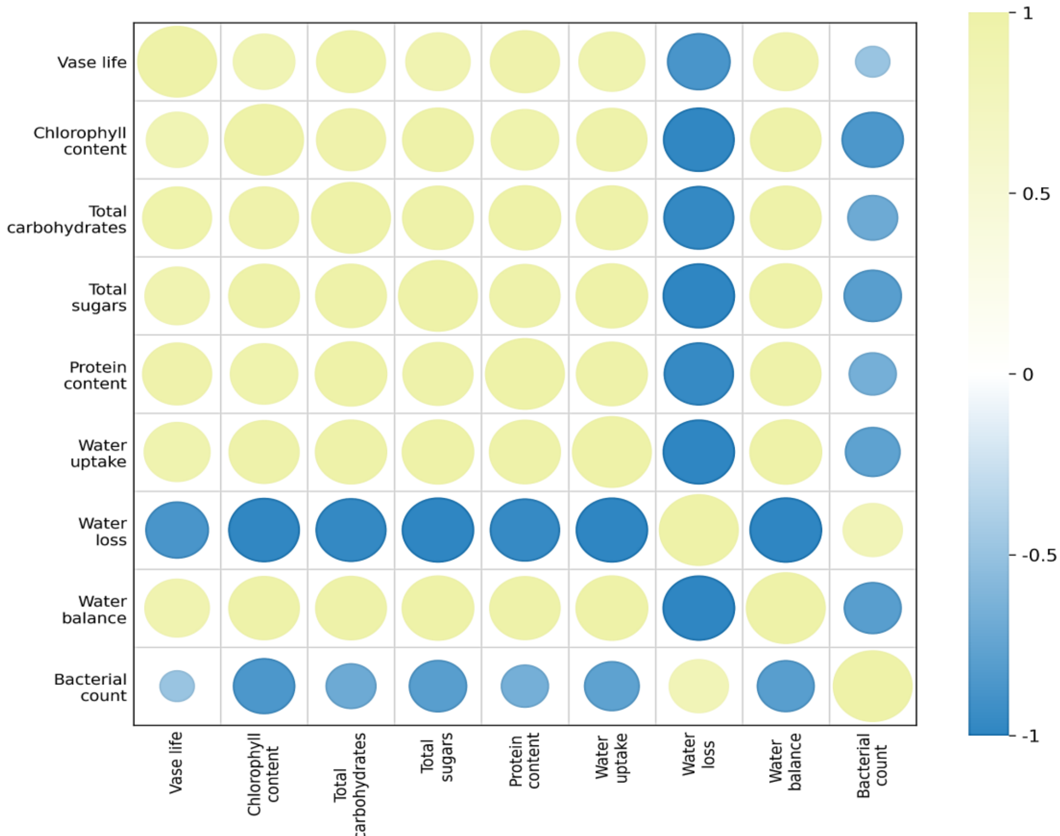

Fig (2): Correlation matrix between vase life and the studied physiological and biochemical parameters of gladiolus cv. White Prosperity cut spikes, based on treatment mean values of the 2024 and 2025 seasons (n = 14). Circle size and color reflect the magnitude and direction of the Pearson correlation coefficient (r); yellow-green denotes positive correlations and blue denotes negative correlations, on a scale from -1 to +1.

Discussion

The longevity of cut flowers is a critical metric for assessing the efficacy of preservation treatments. For ephemeral cut flowers like Gladiolus hybrid cv. White Prosperity, where senescence occurs rapidly, vase life may not adequately represent their postharvest performance. Consequently, it is imperative to account for physiological and biochemical changes during vase life. Gladiolus cut flowers frequently experience microbial growth and xylem obstruction during postharvest storage and vase display, leading to accelerated senescence signs such as petal yellowing and spathe drooping (**Verma and Fatmi, 2022**). Preservative solutions generally comprise water, sugars, antibacterial agents, organic acids, and plant growth regulators. Among them, carbohydrates serve as respiratory substrates and assist in maintaining osmotic balance, both of which are crucial for postponing senescence (**Wei *et al.*, 2025**). Sucrose is the predominant carbon source utilized in these solutions (**Rabiza-Świder *et al.*, 2020**). Moreover, 8-HQ is extensively utilized as an antibacterial agent owing to its capacity to inhibit bacterial proliferation in aqueous solutions.

The present results clearly demonstrate that postharvest holding solutions enriched with gibberellic acid (GA3) and 6-benzylaminopurine (6-BA), particularly the combined treatment of 50 mg/L GA3 + 30 mg/L 6-BA, consistently outperformed the single-hormone and control treatments across all studied morphological, physiological and microbiological traits of gladiolus cv. White Prosperity cut spikes. This synergistic response between a gibberellin and a cytokinin agrees with very recent findings in other ornamental species. In *Anthurium andraeanum*, supplementing a sucrose + 8-hydroxyquinoline holding solution with graded concentrations of 6-BA and GA3 significantly extended vase life and improved postharvest physiological performance relative to untreated controls, confirming that both classes of regulator act as effective senescence-delaying agents when incorporated into preservative solutions (**Huang *et al.*, 2026**). Similarly, pretreatment with gibberellin A3 combined with calcium chloride delayed senescence-associated stem bending and extended the vase life of cut gerbera, underscoring the broad applicability of GA3-based holding treatments across unrelated cut-flower families (**Tonooka *et al.*, 2023**).

The progressive rise in spike and flower fresh weight with increasing GA3 and 6-BA concentration (Tables 1 and 2) is consistent with the established capacity of gibberellins to hydrolyze stored complex carbohydrates into soluble monosaccharides, thereby lowering tissue osmotic potential and promoting greater water influx and turgor retention. A recent comprehensive review of postharvest physiology in tropical and ornamental cut flowers reaffirmed that gibberellin treatment enhances reducing-sugar accumulation and consequently improves water status and fresh weight retention during the vase period, while cytokinins act complementarily by sustaining cell membrane integrity and delaying the onset of tissue dehydration (**Malakar *et al.*, 2023**). The superior performance of the combined GA3 + 6-BA treatment over either hormone applied alone therefore likely reflects an additive contribution of osmotic adjustment, driven mainly by GA3, and membrane stabilization, driven mainly by 6-BA, to overall water and biomass retention.

The marked extension of vase life recorded with the combined 50 mg/L GA3 + 30 mg/L 6-BA treatment, raising longevity by 63.71-66.67% over the control (Table 3), parallels the magnitude of improvement reported very recently for other cytokinin-gibberellin combinations. In cut *Anthurium andraeanum*, the most effective single-hormone treatment (30 mg/L 6-BA) extended vase life by 14.26% relative to untreated controls, while inclusion of GA3 in the same preservative base also sustained chlorophyll retention and delayed visible senescence symptoms (**Huang *et al.*, 2026**). Likewise, application of plant growth regulators including 6-Benzylaminopurine and gibberellic acid was recently shown to significantly affect flower quality and postharvest performance of cut lily relative to untreated stems, confirming the cross-species reliability of cytokinin-gibberellin holding treatments as a strategy for extending the marketable life of cut spikes (**Al-Ajlouni *et al.*, 2023**). The strong response of *Gladiolus cv*. White Prosperity to the combined treatment is particularly encouraging given that this cultivar has previously shown comparatively limited vase life under standard vase-solution treatments (**Verma and Fatmi, 2022**), suggesting that hormonal holding solutions may be especially valuable for cultivars with otherwise short postharvest longevity.

The significant retardation of chlorophyll degradation observed with increasing GA3 and 6-BA concentration, and most strongly with their combination (Table 4), agrees with the well-documented anti-senescence action of cytokinins on photosynthetic pigments. Cytokinins are known to delay chlorophyll breakdown by suppressing chlorophyllase activity and maintaining chloroplast membrane integrity, while gibberellins contribute by retarding the protein degradation that typically accompanies pigment loss. This dual protective mechanism was directly demonstrated in recent work on cut Anthurium spikes, where both 6-BA and GA3 treatments significantly delayed chlorophyll degradation while reducing malondialdehyde accumulation, with chlorophyll content emerging as one of the physiological parameters most strongly correlated with extended vase life (**Huang *et al.*, 2026**). The pronounced chlorophyll retention recorded in the present study with 50 mg/L GA3 + 30 mg/L 6-BA is therefore consistent with a combined suppression of pigment-degrading enzymes and oxidative membrane damage.

The significant increases in total carbohydrate and total sugar content recorded with GA3 and 6-BA, individually and in combination (Tables 5 and 6), can again be linked to the role of gibberellins in mobilizing starch reserves into soluble sugars, which serve both as respiratory substrates and as osmotically active solutes that help maintain petal turgor during senescence. This mechanism has been highlighted in recent reviews of tropical and ornamental cut-flower physiology, which note that gibberellin treatment enhances reducing-sugar accumulation and thereby extends postharvest life by sustaining the energy supply needed for continued metabolic activity in detached spikes (**Malakar *et al.*, 2023**). The further increase in carbohydrate and sugar content observed when GA3 was combined with 6-BA suggests that cytokinin supplementation may additionally help retain sugars within petal tissue by delaying senescence-associated catabolic processes, rather than acting solely through carbohydrate mobilization.

Protein content followed a similar trend, increasing significantly with GA3 and 6-BA application and reaching a maximum with the 50 mg/L GA3 + 30 mg/L 6-BA combination (Table 7). Both gibberellins and cytokinins have been reported to reduce protein degradation in senescing floral tissue, acting as protein and pigment protectors that slow the proteolytic activity normally associated with petal senescence (**Malakar *et al.*, 2023**). In *Anthurium andraeanum*, the maintenance of higher antioxidant enzyme activity (SOD and POD) under combined 6-BA and GA3 treatment was associated with reduced oxidative damage to cellular proteins and membranes, providing a plausible biochemical basis for the protein retention recorded here in gladiolus cv. White Prosperity (**Huang *et al.*, 2026**).

The superior water uptake, reduced water loss and consequently more positive water balance recorded for spikes held in 50 mg/L GA3 + 30 mg/L 6-BA (Table 8) reflect the combined osmotic and membrane-protective actions of the two regulators discussed above. Comparable improvements in water relations following GA3-based postharvest treatment have recently been reported in cut rose, where a gibberellic-acid-based holding composite significantly enhanced water uptake and delayed wilting relative to untreated controls (**El-Naggar *et al.*, 2024**). In Anthurium, treatments that produced the longest vase life were also those that most effectively returned cut spikes to a positive water balance after the initial postharvest decline, reinforcing the close physiological link between hormonal regulation of water relations and overall vase-life extension (**Huang *et al.*, 2026**).

The marked reduction in bacterial counts recorded with increasing GA3 and 6-BA concentration, and most pronounced in the combined treatment (Table 9), may be attributed to the lower availability of leaked sugars and other exudates at the cut stem base, since GA3- and 6-BA-treated spikes retained higher internal carbohydrate and protein pools rather than releasing them into the vase solution where they would otherwise support microbial proliferation. Reduced microbial loading in the holding solution is widely recognized as a key contributor to delayed xylem occlusion and prolonged water uptake in cut flowers, a relationship recently re-emphasized in postharvest reviews of tropical and other ornamental cut flowers, which identify microbial control in vase solutions as one of the most consistently effective interventions for extending shelf life (**Malakar *et al.*, 2023**). The present results suggest that, beyond their direct hormonal effects, GA3 and 6-BA holding solutions may confer an indirect antimicrobial benefit by limiting nutrient leaching into the vase water.

The correlation analysis (Fig. 2) provides an integrated physiological explanation for the superior performance of the combined 50 mg/L GA3 + 30 mg/L 6-BA treatment. The strong positive associations of vase life with chlorophyll content, total carbohydrates, total sugars, protein content and water uptake, together with its strong negative association with water loss, indicate that GA3 and 6-BA prolonged spike longevity through a tightly interconnected network of osmotic, pigment-protective and nutritional effects rather than through any single isolated mechanism. Because almost all of the measured quality traits changed in a coordinated manner across treatments, the maintenance of carbohydrate, protein and water status emerges as the central physiological axis underlying the extension of vase life in this study. The comparatively weaker correlation between vase life and bacterial counts relative to the other physiological traits further suggests that, while microbial control in the holding solution contributed to extended longevity, it played a secondary, supportive role to the hormone-driven maintenance of internal carbohydrate, protein, pigment and water status. A similarly close association between vase life and physiological indicators such as chlorophyll retention, antioxidant enzyme activity and malondialdehyde accumulation has recently been reported for cut Anthurium and rose spikes treated with GA3 and 6-BA (**El-Naggar *et al.*, 2024**; **Huang *et al.*, 2026**), supporting the view that correlation-based analysis of postharvest physiological traits is a useful diagnostic tool for identifying the principal determinants of vase life across diverse cut-flower species.

Taken together, the present findings confirm that gladiolus cv. White Prosperity responds strongly and consistently to postharvest cytokinin-gibberellin treatment, with the combination of 50 mg/L GA3 + 30 mg/L 6-BA producing the greatest improvements in flower weight, vase life, chlorophyll retention, carbohydrate and protein status, water relations and microbial control. These results agree closely with a growing body of very recent literature confirming the synergistic senescence-delaying action of combined gibberellin-cytokinin holding solutions across diverse cut-flower species, including gerbera (**Tonooka *et al.*, 2023**), lily (**Al-Ajlouni *et al.*, 2023**), rose (**El-Naggar *et al.*, 2024**) and *Anthurium andraeanum* (**Huang *et al.*, 2026**). Given that gladiolus cv. White Prosperity has previously shown comparatively short vase life under standard vase-solution treatments (Verma and Fatmi, 2022), the combined GA3 + 6-BA holding solution evaluated here offers a practical, low-cost strategy that floriculture growers and exporters could adopt to substantially extend the marketable life and visual quality of this widely cultivated cultivar.

Conclusion

On the basis of the two seasons of evaluation, it can be concluded that postharvest holding solutions enriched with gibberellic acid (GA3) and 6-benzylaminopurine (6-BA) significantly improved the keeping quality of gladiolus cv. White Prosperity cut spikes, with all single and combined hormone treatments outperforming the distilled-water control across every parameter measured. The treatment combining 50 mg/L GA3 with 30 mg/L 6-BA was consistently the most effective, producing the highest flower and plant fresh weight, the longest vase life (an increase of 63.71-66.67% over the control), the greatest retention of total chlorophyll, total carbohydrates, total sugars and protein content, the most favorable water relations (highest water uptake and water balance with the lowest water loss), and the lowest bacterial counts in the vase solution during both the 2024 and 2025 seasons.

These findings indicate that the beneficial effects of GA3 and 6-BA on postharvest performance of gladiolus cv. White Prosperity are largely additive, with GA3 contributing mainly through carbohydrate mobilization and osmotic adjustment and 6-BA contributing mainly through chlorophyll and protein retention and suppression of microbial proliferation in the vase solution. Accordingly, a holding solution containing 50 mg/L GA3 + 30 mg/L 6-BA can be recommended as a practical, low-cost postharvest treatment for commercial growers, wholesalers and exporters seeking to extend the vase life and maintain the visual and nutritional quality of gladiolus cv. White Prosperity cut spikes during marketing and transport. Further studies, including the combination of these regulators with sucrose, antimicrobial agents or other plant growth regulators under varying storage temperatures, are recommended to optimize this treatment further and to clarify the underlying biochemical and molecular mechanisms of cytokinin-gibberellin synergy in delaying gladiolus spike senescence.

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