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POSTHARVEST LONGEVITY AND PHYSIOLOGICAL CHANGES IN CUT ASPARAGUS PLUMOSUS FOLIAGE AS INFLUENCED BY PREHARVEST AND POSTHARVEST TREATMENT OF SALICYLIC ACID AND GIBBERELLIC ACID

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abstract – *Asparagus plumosus* have plenty of applications in floral decoration, but its postharvest longevity is short. So, the present research aimed to improve vase life and some physiological parameters of this plant species in a factorial experiment based on a randomized complete block design with 16 treatments and three replications. The experimental treatments included two plant growth regulators of gibberellic acid (GA_3) and salicylic acid (SA) at four rates (0, 100, 200, and 400 µmol) and two application methods of foliar application at the preharvest phase and application in the preservative solution at the postharvest phase. In both application methods, SA and GA_3 improved all traits versus the control irrespective of the application method. However, the combined application of 100 and 200 µmol of GA_3 and SA exhibited the best results and the longest vase life. The weakest results among different rates were obtained from increasing the application rate of SA and GA_3 to 400 µmol. In general, the best treatments for improving the vase life and related traits were SA100 + GA200 in the foliar application and SA200 + GA100 in the vase solution application. So, they are recommended for preserving the postharvest quality of this plant species.

Keywords: antioxidant enzymes, foliar application, growth regulators, malondialdehyde.

Introduction

The production and export of foliage plants alongside cut and pot flowers have had an ascending trend in flower-producing and exporting countries in recent years. Foliage flowers are a major element in floriculture, especially floral design and decoration. In addition to their beautifying role, these flowers are used as fillers in flower bouquets and baskets. The foliage flower most commonly used in floral design is *Asparagus plumosus*, which provides one of the most popular ornamental leaves in flower decoration. *A. plumosus* is a perennial herbaceous plant with strong green stalks and flat and feather-like leaves from the family of Asparagaceae that is mainly cultivated to produce ornamental leaves in floriculture (Safeena et al., 2014; Chowdhuri et al., 2021).
As with cut flowers, postharvest shelf life is a key factor in assessing cut foliage quality and commercial value. Ornamental foliage plants like *A. plumosus* immediately lose their ornamental value after detachment from their maternal plants due to leaf shedding, early withering, and/or leaf bleaching or browning (Safeena et al., 2014). So, extending postharvest longevity is necessary to preserve cut foliage ornamental and commercial value. Various processes are involved in accelerating the senescence of cut flowers and foliage, including the inability of the cut part to take up water due to the activity of microorganisms and ethylene sensitivity. Extensive research, especially on cut flowers,

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Table 1. The comparison of the mean effects of different treatments (pre-harvest) on the studied parameters of *Asparagus plumosus* *

Treatment	Total chlorophyll content (mg g^{-1} F.W.)	Electrolyte leakage (%)	Relative solution uptake (%)	Bacterial load (%)	Relative water content (%)	MDA (mMol g^{-1} F.W.)	CAT (units g^{-1} F.W. min^{-1})	SOD (units g^{-1} F.W. min^{-1})	POD (units g^{-1} F.W. min^{-1})
Control	1.53 f	36.76 a	49.50 f	7.29 a	60.17 i	52.95 a	1.17 e	1.25 e	0.78 j
GA_{100}	2.64 bc	19.37 de	81.45 a-d	1.94 cde	80.08 c	19.57 h	3.23 b	3.20 abc	2.17 de
GA_{200}	2.64 bc	18.78 f	80.82 a-d	1.92 cde	80.33 c	19.37 h	3.30 ab	3.21 abc	2.25 d
GA_{400}	2.44 de	20.38 bc	75.92 cde	1.94 cde	73.68 h	23.08 c	3.18 bc	2.98 bcd	1.36 i
SA_{100}	2.73 ab	19.14 e	81.62 abc	1.93 cde	79.99 c	18.28 i	3.29 ab	2.65 d	2.06 e
SA_{100}-GA_{100}	2.70 ab	18.66 fg	83.49 a	1.90 cde	81.88 b	18.68 i	3.30 ab	3.21 abc	2.54 c
SA_{100}-GA_{200}	2.86 a	17.26 i	83.58 a	1.88 e	82.66 ab	16.95 j	3.39 a	3.39 a	3.51 a
SA_{100}-GA_{400}	2.55 bcd	20.19 c	78.18 a-e	1.97 cd	74.13 gh	22.58 de	3.23 bc	3.09 abc	1.60 gh
SA_{200}	2.65 bc	18.71 f	73.88 e	1.95 cde	80.49 c	19.24 h	3.27 ab	3.16 abc	2.26 d
SA_{200}-GA_{100}	2.68 abc	18.36 g	82.51 ab	1.92 cde	81.91 b	18.25 i	3.37 a	3.32 ab	2.98 b
SA_{200}-GA_{200}	2.75 ab	17.73 h	83.77 a	1.89 de	83.03 a	17.13 j	3.39 a	3.32 ab	3.45 a
SA_{200}-GA_{400}	2.62 bcd	19.30 de	78.42 a-d	1.94 cde	78.33 d	21.37 f	3.22 bc	3.22 abc	1.83 f
SA_{400}	2.43 de	20.42 bc	76.59 b-e	1.98 c	74.99 fg	22.34 e	3.11 cd	3.17 abc	1.40 i
SA_{400}-GA_{100}	2.49 cde	20.26 bc	77.76 a-e	1.97 c	75.15 f	23.02 cd	3.21 bc	3.12 abc	1.69 fg
SA_{400}-GA_{200}	2.49 cde	19.50 d	78.11 a-e	1.94 cde	77.39 e	20.71 g	3.28 ab	3.16 abc	1.83 f
SA_{400}-GA_{400}	2.33 e	20.56 b	75.08 de	2.09 b	74.00 h	24.15 b	3.07 d	2.91 cd	1.45 hi

*In each column, averages that have at least one common letter are in statistically similar groups with Duncan's multiple range tests at the $P < 0.01$ level.

has revealed that SA and GA_3 are effective compounds in retarding senescence and preserving postharvest longevity (Alaey et al., 2011; Saeed et al., 2014; Abbasi et al., 2019). Salicylic acid (SA) is a naturally-occurring simple phenolic compound that is synthesized in plant cells and acts as a signaling molecule in preserving plant resistance to biotic and abiotic stresses, e.g., plant resistance to pathogens (Murphy et al., 2020). Although SA is recognized as a defensive hormone in plants, it plays a regulating role in all physiological processes of plants during their growth and development. SA is extensively applied as a safe and environmentally-friendly compound at preharvest and postharvest stages. Previous research has shown that SA plays an essential role in regulating and controlling the senescence process, scavenging free radicals, strengthening the antioxidant system, preserving membrane stability, and maintaining postharvest quality (Xiang et al., 2021; ul Haq et al., 2022). Furthermore, the antimicrobial activity of SA and its effects on stomatal closure, respiration suppression, ethylene synthesis, and the retardation of the postharvest aging trend have been documented (Alaey et al., 2011; ul Haq et al., 2022). The increase in vase life and its related traits with SA application has been reported in the cut flowers of roses (Alaey et al., 2011), iris (Ramzan et al., 2018), and lily (Abbasi et al., 2019), reflecting the effectiveness of the compound in preserving postharvest longevity. SA inhibits pathogen growth in plants through repression of the auxin signaling pathway, which causes the global repression of auxin-related genes, including the TIR1 receptor gene, resulting in the stabilization of the Aux/IAA repressor proteins and inhibition of auxin responses (Wang et al., 2007). SA prevents the conversion of ACC to ethylene by reducing the production and activity of ACC oxidase. SA was also found to inhibit the wound-induced accumulation of the ACC synthase transcript in tomato (Wei et al., 2011). According Wei et al. (2011) report, SA could be considered for commercial application to maintain the quality and antioxidant properties of asparagus. SA treatments may enhance cut flower longevity by promoting membrane stability and maintaining water uptake. SA is an acid that can function as signal molecules in promoting plant defence responses. SA and JA markedly stretched the vase life of cut *Acacia holosericea* foliage by inhibiting water loss and maintaining relative fresh weight during the vase life (Chen & Joyce, 2016).

Gibberellic acid (GA_3) is the most common gibberellic used in horticulture. This plant growth regulator participates in all physiological processes during plant growth and development, from germination to aging and even during storage and postharvest life. GA_3 is an anti-aging compound and prevents pigment degradation in plant tissues (Ferrante

Table 2. The comparison of the mean effects of different treatments (post-harvest) on the studied parameters of *Asparagus plumosus* *

Treatment	Total chlorophyll content (mg g^{-1} F.W.)	Electrolyte leakage (%)	Relative solution uptake (%)	Bacterial load (%)	Relative water content (%)	MDA (mMol g^{-1} F.W.)	CAT (units g^{-1} F.W. min^{-1})	SOD (units g^{-1} F.W. min^{-1})	POD (units g^{-1} F.W. min^{-1})
Control	1.24 f	37.85 a	48.22 j	7.76 a	59.35 h	54.17 a	1.34 e	1.35 g	0.92 l
GA_{100}	2.13 e	23.15 g	76.67 e	2.12 cd	74.35 e	21.18 f	2.74 d	3.13 bcd	2.28 fg
GA_{200}	2.27 b-e	21.75 i	80.05 c	2.08 cd	76.54 d	20.39 h	3.16 abc	3.21 ab	2.43 e
GA_{400}	2.20 cde	23.46 fg	74.06 h	2.15 cd	72.90 f	23.58 c	3.11 abc	3.02 de	1.55 k
SA_{100}	2.24 b-e	22.59 h	77.07 e	2.08 cd	74.97 e	21.32 f	3.11 abc	3.09 bcd	2.23 g
SA_{100}-GA_{100}	2.29 a-e	20.72 j	80.99 b	2.12 cd	77.40 c	19.97 i	3.33 ab	3.26 a	2.67 d
SA_{100}-GA_{200}	2.29 a-e	20.45 j	80.51 c	2.10 cd	77.89 c	19.78 ij	3.21 abc	3.21 ab	3.21 c
SA_{100}-GA_{400}	2.29 a-e	24.21 cd	75.28 g	2.15 cd	73.29 f	23.39 c	3.11 abc	3.05 de	1.74 j
SA_{200}	2.33 abc	20.68 j	79.45 d	2.12 cd	76.28 d	20.72 g	3.17 abc	3.20 abc	2.40 ef
SA_{200}-GA_{100}	2.44 a	19.67 k	81.93 a	1.99 d	80.76 a	19.56 j	3.32 ab	3.31 a	3.60 a
SA_{200}-GA_{200}	2.37 ab	19.58 k	81.05 b	2.00 d	79.98 b	19.81 ij	3.34 a	3.26 a	3.38 b
SA_{200}-GA_{400}	2.29 a-e	23.57 ef	75.97 f	2.12 cd	74.43 e	22.92 d	3.17 abc	3.08 cd	2.04 h
SA_{400}	2.25 b-e	24.44 bc	74.42 h	2.19 c	72.64 f	23.64 c	3.04 bc	3.05 de	1.60 k
SA_{400}-GA_{100}	2.25 b-e	23.88 de	75.92 f	2.21 c	73.02 f	22.78 d	3.01 c	2.95 e	1.90 i
SA_{400}-GA_{200}	2.32 a-d	24.24 cd	75.83 f	2.24 c	74.76 e	22.39 e	3.10 abc	3.10 bcd	2.00 hi
SA_{400}-GA_{400}	2.17 de	24.71 b	73.42 i	2.66 b	71.00 g	24.66 b	2.97 cd	2.69 f	1.64 jk

*In each column, averages that have at least one common letter are in statistically similar groups with Duncan's multiple range tests at the $P < 0.01$ level.

et al., 2009; Miceli et al., 2019; Xiao et al., 2022). In Zhang et al.'s (2022) research, the postharvest application of GA_3 contributed to preserving growth, chlorophyll content, the activity of antioxidant enzymes, and postharvest quality and longevity of lilies. Saeed et al. (2014) reported that the foliar treatment of gladiolus with 25 mg/l GA_3 resulted in preserving membrane stability and antioxidant activity and extending vase life. The positive effects of GA_3 have also been reported on the longevity and postharvest quality of lettuce and *Eruca sativa* (Miceli et al., 2019) and okras (Xiao et al., 2022). Experiment was done to assess the effects of GA (0.25 mmol·dm^{-3} GA_3) as well as the Dutch commercial conditioners on the senescence of cut foliage of *Asparagus densiflorus* 'Meyerii'. An growth in the proteolytic activity was detected during shoot senescence with simultaneous reduction in soluble proteins and accumulation of free amino acids and proline. Postharvest treatments significantly impacted the rate of the above alterations (Rabiza-Świder & Skutnik, 2009; Safeena, 2013). The results of Rabiza-Świder et al. (2009) study clearly indicate that GA_3 or Chrysal SVB® can perform their positive effects in lengthening the vase life of cut *A. densiflorus* 'Myriocladus' shoots, by delaying some senescence-related activities in their cladodes.

Given the significance of *A. plumosus* as one of the most widely used ornamental foliage in floral design and the positive effect of GA_3 and SA in extending the longevity of perishable horticultural products, the present research aimed to shed light on the effect of these two growth regulators at the preharvest and postharvest stages on the vase life and related traits of cut *A. plumosus* foliage. This test surveyed potentially beneficial effects of GA_3 and SA vase solution treatments on vase life reactions and longevity of cut A. plumosus foliage.

Materials and Methods

To study the effect of growth regulators on the postharvest longevity of cut *Asparagus plumosus* foliage, a factorial experiment was conducted based on a randomized complete block design with three replications. The experimental treatments included two growth regulators (GA_3 and SA) at four rates (0, 100, 200, and 400 µmol) and two application times (preharvest as foliar application and postharvest in vase solution). For the experiment, 480 pot plants of *A. plumosus* that were similar in age, size, and maturity level were procured from a commercial greenhouse in Amol, Mazandaran and were immediately transferred to

a greenhouse with standard and uniform conditions for all plants (24±2°C and 60-70% relative humidity) and were used as the plant material. The experiment was carried out in two phases (preharvest and postharvest). In the first phase, 240 plants were sprayed with different rates of SA and GA_3 two weeks before commercial maturity. The plants were sprayed only once with 500 ml solution/plant so that the surface of all the plants was wet after the foliar application and the solution drops were flowing on their leaves. Two weeks after the foliar application (at the commercial maturity stage), one branch was detached from each plant and sent to the postharvest laboratory of Science and Research Branch of Islamic Azad University for the study of postharvest longevity. At the laboratory, all branches were cut to the same length, and after weighing, they were re-cut under water to avoid vascular blockage. They were then put in vases containing 250 ml of the vase solution (water + sucrose 3% + 8-hydroxyquinoline sulfate) and were kept there until the end of their vase life. The vases were kept in a room at a temperature of 20±2°C, relative humidity of 70-75%, and 12 hours of daylight with a light intensity of 15 µmol/m^2/s throughout the experiment.

In the second phase, the 240 *A. plumosus* plants, which had not been sprayed at the preharvest stage, were used. The branches were cut from their material plants at the commercial maturity stage and were transferred to the laboratory as soon as possible. At this stage, different rates of GA_3 and SA were used as the vase solution and distilled water was used as control. The procedure for preparing and keeping the cut foliage for the assessment of postharvest parameters was similar to the first phase.

The flowers were daily visited to register the target parameters. The vase life was calculated by counting days from foliage harvest from the material plants until the shedding and withering of 30% of the foliage. Vase life was recorded in days. The end of vase life was defined as the point when 30% of the shoots showed signs of yellowing or drying out (Skutnik et al., 2006).

Some other recorded traits included relative uptake of solution, relative water content (Sedaghathoor et al., 2020), bacterial load (Knee, 2000), total chlorophyll (Arnon, 1949), electrolyte leakage (Zhao et al., 1992), malondialdehyde (MDA) content (Stewart & Bewley, 1980), and the activity of catalase, superoxide dismutase, and peroxidase (Mazumdar & Majumder, 2017). To measure the water content of the petals, they were weighed on the first and final day of the experiment and their fresh weight was recorded. Then, they were oven-dried at 60°C for 72 hours and their dry weight was recorded. The following equation was employed to measure the rate of solution uptake (Sedaghathoor et al., 2020).

$$\text{Solution uptake rate} = \frac{\text{Daily weight of foliage - weight on 1 st day}}{\text{Weight on 1 st}} \times 100$$

The activity of catalase was measured through the following stages (Mazumdar & Majumder, 2017): 1 g of plant tissue that had been ground in 4 ml ethanol was added with (i) 0.01 mol phosphate buffer (pH = 7), (ii) 0.5 ml H2O2 0.2 mol, and (iii) 2 ml acid reagent (dichromate/acetic acid mixture). Then, its absorption was read at 610 nm with a spectrophotometer. To measure the enzymatic activity of peroxidase (POD), the extract was prepared as described

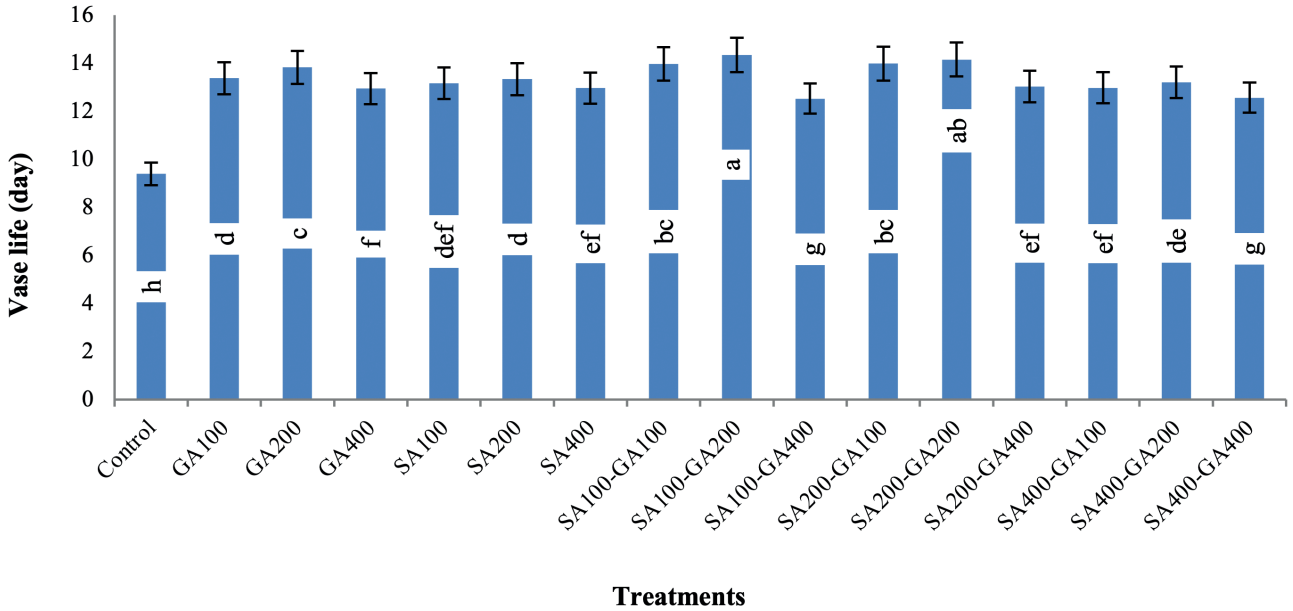

Figure 1. The effect of the foliar application of SA and GA_3 at different rates on the vase life of *Asparagus plumosus.*

above. Then, the variations of OD were read at 430 nm with a spectrophotometer once thirty seconds for two minutes (Mazumdar and Majumder, 2017). At the end of the experiment and after data collection, they were subjected to variance analysis (ANOVA) in MSTATC and the comparison of means by Tukey test at the 1% and 5% probability levels.

Results

The comparison of means for the effect of the preharvest foliar application of growth regulators on the recorded traits of *A. plumosus* revealed that the application of SA and GA_3, separately and together, significantly increased total chlorophyll content, relative solution uptake, relative water content, and the activity of antioxidant enzymes. Also, the preharvest foliar application of SA and GA_3 was significantly related to lower bacterial load, electrolyte leakage (EL), and MDA accumulation than the control (Table 1). The comparison of means for the application of SA and GA_3 at the preharvest step showed the positive and significant effect of their application, both separately and together, on extending the vase life of *A. plumosus* so that the control had the shortest vase life (9.40 days) and SA_{100} + GA_{200} had the longest vase life (14.35 days). SA_{200} + GA_{200} exhibited the second-longest vase life (Figure 1). According to the results, the most effective treatments in extending the vase life and improving the recorded parameters were SA_{100} + GA_{200} and SA_{200} + GA_{200}. Based on Table 1, SA_{100} + GA_{200} treatment resulted in the highest values of total chlorophyll, relative solution uptake, CAT and SOD activities. While this treatment caused to the lowest amount of bacterial load and electrolyte leakage. Thus, SA_{100} + GA_{200} was one of the effective treatments for *Asparagus plumosus* cut foliage. It can be concluded that the highest electrolyte leakage and MDA were related to the control treatment, which indicates in the pre-harvest experiment, positive effects were observed with the application of trial PGRs compared to the control (Table 1).

Table 2 presents the effect of SA and GA_3 application at the postharvest phase and as the vase solution on the physiological parameters of the cut *A. plumosus* foliage. Similar to the results of the preharvest phase, the application of SA and GA_3, either separately or combination, improved the recorded parameters versus the control significantly. According to the results, SA_{200} + GA_{100} and SA_{200}+ GA_{200} were the first and second-best treatments as they improved most recorded traits, respectively (Table 2). The comparison of means revealed that the application of SA and GA_3-containing vase solution extended the vase life versus the control (9.49 days). The lowest vase lives were obtained from the treatments of SA_{200} + GA_{100} (14.15 days), SA_{200} + GA_{200} (14.06 days), and SA_{100} + GA_{200} (14.02 days) (Figure 2).

But the interesting result is that in the post-harvest test, the aforementioned traits (i.e. EL, bacterial load and MDA) had the same results as the pre-harvest test under the control, so that the highest value of EL, bacterial load, and MDA were related to control the same as preharvest experiment. In the post-harvest experiment, the highest values of of total chlorophyll, relative solution uptake and CAT activities were

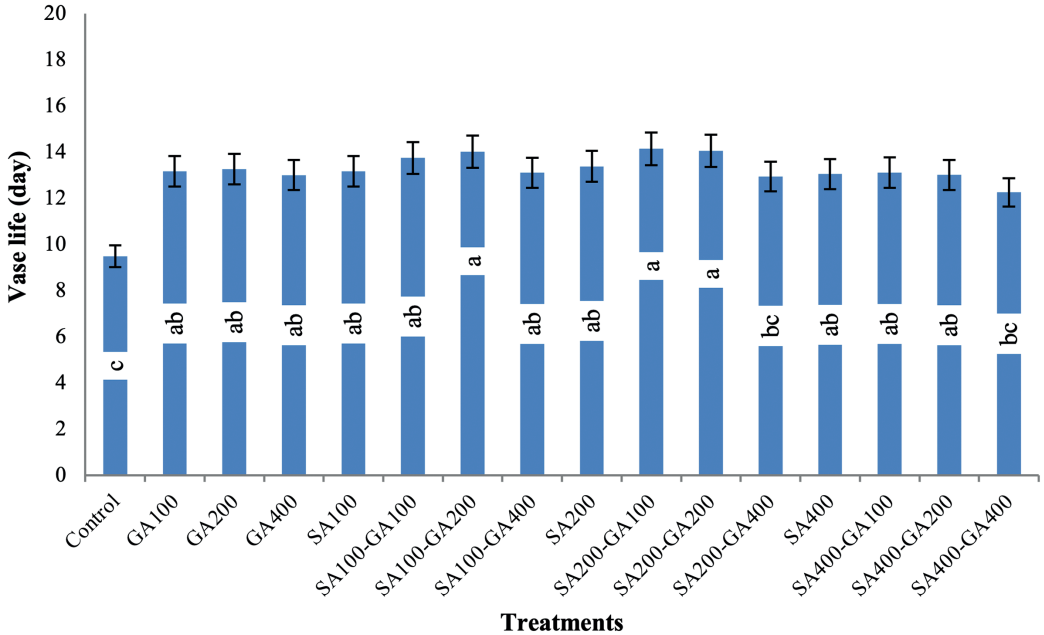

Figure 2. The effects of vase solution containing SA and GA_3 at different rates on the vase solution of *Asparagus plumosus*.

associated to combination treatment of SA + GA as well as pre-harvest test, but, in post harvest test, treatment SA_{200} + GA_{100} resulted in the highest value of total chlorophyll, relative solution uptake, CAT and SOD activities (Table 2). It seems that, unlike the pre-harvest test, the high concentration of SA (200) is more effective in the post-harvest test.

Discussion

Postharvest longevity is the most important qualitative parameter that determines the commercial value of all fresh and perishable products, like cut flowers and foliage. One of the most important factors that accelerate the aging and withering of the flowers and foliage detached from the maternal plants is the disruption in water uptake. Vascular blockage by microbial and bacterial factors is an essential impediment to water uptake by cut branches (Alaey et al., 2011). So, the elimination of bacteria from vase solutions and stem ends can contribute to improving vase life. In the present research, the separate and simultaneous application of SA and GA_3 at both preharvest and postharvest phases and at all rates reduced bacterial load versus the control, which was accompanied by an increase in solution uptake and relative water content. SA is an anti-stress compound that increases water uptake in plants by influencing the accumulation of compatible osmolytes (ul Haq et al., 2022). In the present research, the lowest solution uptake was observed in the control whereas the application of SA and GA_3, either separately or together, increased the solution uptake of the cut foliage by over 1.5 times. Since solution uptake by cut foliage is related to bacterial load, we observed that it was increased by reducing the bacterial load. Of course, different species and cultivars of *Asparagus* have different responses to water uptake. So that water uptake of cut 'Myriocladus' foliage was almost double that of cut *A. plumosus* foliage, perhaps due to different morphology of transpiration apparatus. (Marino et al., 2003). SA has anti-microbial activity (ul Haq et al., 2022), so its effect on reducing the microbial load is not surprising. On the other hand, it has been reported that SA results in stomatal closure in adverse conditions to reduce water loss by transpiration (ul Haq et al., 2022), It can, therefore, be said that SA helped preserve water uptake and even relative water content of the cut *A. plumosus* foliage by performing multiple functions, including the reduction of bacterial load and the reduction of transpiration. Similar results have been reported by Alaey et al. (2011) for cut roses and ul Haq et al. (2022) for cut *Consolida ajacis* spikes.

GA_3 plays a key role in making a balance in the water content of plant cells (Janowska et al., 2013; Ulczycka-Walorska & Krzymińska, 2022). Stephen et al. (2005) reported that GA_3 improved water uptake and relative water content in plant tissues by increasing cell wall flexibility. Mashahiri & Asil (2018) reported the increased uptake of water and relative water content in cut daffodil flowers with GA_3 application. They argue that GA_3 creates negative water potential in cells by facilitating the decomposition of complicated carbohydrates into simple sugars and their accumulation in cells, thereby enabling cells to take up more water and increase their relative water content. Similar results have been reported by Emongor (2004) for gerbera and Pinto et al. (2007) for *Calathea louisae*. In addition, GA_3 has been reported to reduce bacterial accumulation and inhibit vascular blockage (Singh et al., 2008). So, the preservation of relative water content in the cut *A. plumosus* foliage by the preharvest and postharvest application of SA and GA_3 can be ascribed to their impact on reducing bacterial load, decreasing cell water potential, preserving water uptake, and reducing water loss.

Yellowing or chlorophyll degradation in ornamental foliage plants and green parts of plants is a symptom of aging and the loss of postharvest commercial value (Supapvanich & Promyou, 2013; Xiao et al., 2022). One key problem of *A. plumosus* is the early yellowing of leaves at the postharvest stage (Safeena et al., 2014). As was already mentioned in the results, SA and GA_3 were beneficial for preserving leaf chlorophyll at both preharvest and postharvest stages. There are reports as to chlorophyll preservation in the cut foliage of *Clathea* (Pinto et al., 2007), citrus (Porat et al., 2001), and *Limonium latifolium* (Janowska et al., 2013) with GA_3 application. Porat et al. (2001) state that GA_3 application timing (preharvest and postharvest) does not affect chlorophyll significantly. We also observed that although chlorophyll content was higher when GA_3 and SA were applied at the postharvest phase, the difference was extremely slight. Rouhi et al. (2014) reported that GA_3 prevented pigment degradation and early withering by acidifying cell sap. Similarly, Stephen et al. (2005) attribute the positive effect of GA_3 on chlorophyll preservation to its structural role in chloroplast structure and its effect on photosynthesis. Ethylene is the main cause of chlorophyll degradation. So, the inhibition of its synthesis and activity can help chlorophyll preservation. SA is an ethylene suppressor and contributes to preserving chlorophyll by suppressing ethylene synthesis (Horváth et al., 2007; Supapvanich & Promyou, 2013). Wei et al. (2011) revealed that SA application (0.1 mmol/l) over six days of asparagus storage helped its chlorophyll preservation, but increasing its rate to 1 mmol/l had a negative effect on this trait. We found that the combined application of the highest rates of GA_3 and SA did not have an acceptable impact on chlorophyll preservation compared to their lower rates. In the study of Dolci et al. (1989), during vase life both species of *Asparagus* showed progressive senescence characterised

by yellowing and falling of cladodes. The vase life of cut *A. plumosus* ranged between 22 and 24 days.

The increased activity of reactive oxygen species (ROS), damages to membrane structure, electrolyte leakage, and MDA accumulation are the major indicators of aging initiation in plants (ul Haq et al., 2022). The excessive amount of ROS and its activity in cells cause oxidative stress, disrupt the physiological functioning of the plant, and injure membrane and macromolecules. Normally, plants scavenge ROS and maintain its balance in their tissues by increasing antioxidant activity. But, as aging proceeds, ROS synthesis and activity sharply increase, resulting in membrane degradation and finally, cell death (Shabanian et al., 2019; ul Haq et al., 2022). SA is an anti-stress hormone that builds a strong defense against oxidative stress by increasing the activity of antioxidant enzymes. By enhancing the activity of POD, SOD, CAT, and APX enzymes, SA helps scavenge ROS, protect the health and integrity of membrane structure, and prevent electrolyte leakage and MDA accumulation. Supapvanich & Promyou (2013) also reported the stimulated activity of antioxidant enzymes (POD, SOD, and CAT) and the reduction of lipid peroxidation by SA. Singh et al. (2008) found that GA_3 application in the vase solution of gladiolus contributed to sustaining antioxidant activity, preserving membrane structure, and delaying aging and death of petals. Researchers argue that GA_3 prevents cell sap acidification by decomposing proteins and degrading cell membrane in cut daffodil flowers (Mashahiri & Asil, 2018). The preservation of membrane stability, the reduction of MDA accumulation, and the increase in the activity of antioxidant enzymes have been reported in cut gladiolus (Saeed et al., 2011) and lily 'Caroline' flowers (Zhang et al., 2022) with GA_3 application, which is consistent with our results.

As is known, the occurrence and acceleration of aging at the postharvest stage depend on many environmental, physical, and chemical factors in addition to detachment from the material plant. These factors trigger destructive changes in biochemical and physiological processes in cut foliage. These changes are typically accompanied by a decrease in water uptake, an increase in water loss, a decrease in fresh weight, an increase in lipid peroxidation, the acceleration of electrolyte leakage, MDA accumulation, the decomposition of macromolecules, and the death (Lone et al., 2021). As with all plant growth and development processes, aging is also controlled by growth regulators (Alaey et al., 2011; Miceli et al., 2019). We found that the separate or simultaneous application of GA_3 and SA extended the vase life of *A. plumosus* versus the control irrespective of the application time by reducing bacterial load, preserving solution uptake, relative water content, chlorophyll content, and membrane integrity, and increasing the activity of antioxidant enzymes. Also, these compounds were more effective when they were applied together. The best results for these traits were obtained from the foliar application of SA_{100} + GA_{200} at the preharvest phase and the application of SA_{200} + GA_{100} at the postharvest phase. Although there were no significant differences among different rates of SA and GA_3 in improving these traits, the application of higher rates of these compounds (400 µmol) had weaker results than their 100 and 200 µmol levels. Supapvanich & Promyou (2013) state that the appropriate concentration of SA varies with plant species. In some species, its higher concentrations have adverse consequences of increasing lipid peroxidation and decreasing longevity. There are reports about the desirable effect of GA_3 on extending the vase life of *Calathea louisae* (Pinto et al., 2007), *Limonium latifolium* (Janowska et al., 2013), gladiolus (Saeed et al., 2014), and lily 'Caroline' (Zhang et al., 2022) and the positive effect of SA on the vase life of rose (Alaey et al., 2011), iris (Ramzan et al., 2018), and lily (Abbasi et al., 2019), which corroborate our findings.

Conclusions

The preservation of postharvest quality and longevity of *A. plumosus* by applying safe compounds is of high significance for its commercial value and marketability in national and international markets. SA and GA_3 are used as well-known vase compounds for improving the longevity and quality of cut flowers. However, given the different responses of species and plant organs to these extending compounds, the present research was conducted on the foliage of *A. plumosus* at the preharvest and postharvest stages. Based on the results, the application of SA and GA_3 at low rates (100 and 200 µmol) and their combined effect improved the postharvest longevity of *A. plumosus*. The most effective treatment for improving the vase life and related traits was SA_{100} + GA_{200} in the foliar application and SA_{200} + GA_{100} in the vase solution application. These two treatments are, therefore, recommended for extending the postharvest shelf life of this plant species.

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