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SCIENTIFIC ARTICLE

Pre and post-harvest effect of gibberellic acid and salicylic acid on cut branches of *Asparagus umbellatus*

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Abstract

Asparagus umbellatus is one of the most popular cut foliage plants that widely used in decorations and bouquets. However, there was a lack of information concerning *Asparagus* postharvest handling. Therefore, in this study, two growth regulators gibberellic acid (GA) and salicylic acid (SA) on concentrations of 0, 100, 200, and 400 µM were applied in two stages viz., pre and postharvest, separately and in combination. Experimental traits including; chlorophyll content, electrolyte leakage, solution uptake, microbial population, relative water content (%), malondialdehyde content, catalase, superoxide dismutase, and peroxidase activity along with plant vase life were evaluated. The results showed that the application of GA and SA lead to significantly extension of the vase life compared to the control. Vase life difference between control (9.34 days) and the superior treatment i.e. GA_{200}+SA_{200} (14.07 days) was more than 50%. Also, the pre-harvest foliar application of GA and SA increased the vase life slightly compared to the application in vase solution. The extended vase life in the per-harvest experiment was obtained using SA_{100}+GA_{100} and SA_{200}+GA_{200} treatments.

Keywords: asparagus, enzymatic activity, growth regulators, vase life.

Resumo

Efeito pré e pós-colheita de ácido giberélico e ácido salicílico em ramos cortados de *Asparagus umbellatus*

Asparagus umbellatus é uma das plantas de folhagem de corte mais populares e amplamente utilizadas em decoração e buquês. No entanto, existe falta de informações sobre o manuseio pós-colheita do aspargo. Portanto, neste estudo, dois reguladores de crescimento ácido giberélico (GA) e ácido salicílico (SA) nas concentrações de 0, 100, 200 e 400 µM foram aplicados em duas etapas, pré e pós-colheita, separadamente e em combinação. Foram analizados os teores de clorofila, vazamento de eletrólitos, absorção de solução, população microbiana, teor relativo de água (%), teor de malondialdeído, catalase, superóxido dismutase e atividade de peroxidase juntamente com a vida de vaso da planta. Os resultados mostraram que a aplicação de GA e SA levou ao prolongamento significativo da vida de vaso em relação ao controle. A diferença de vida do vaso entre o controle (9,34 dias) e o tratamento superior, ou seja, GA_{200}+SA_{200} (14,07 dias) foi superior a 50%. Além disso, a aplicação foliar pré-colheita de GA e SA aumentou ligeiramente a vida de vaso em comparação com a aplicação em solução de vaso. A vida de vaso estendida no experimento por colheita foi obtida usando os tratamentos SA_{100}+GA_{100} e SA_{200}+GA_{200}.

Palavras-chave: aspargos, atividade enzimática, reguladores de crescimento, vida de vaso.

Introduction

Ornamental plant and cut flowers have been part of human life, and a glance at the sales and export statistics of a variety of ornamental species is of great importance in today's world. Cut foliages assume a significant place in ornamental crops markets and it makes up an important section of floral industry. Cut foliages are used in large quantities for floral decoration either on its own or in association with flowers in bouquets and flower arrangements. They are gaining growing popularity due to variation of floriculture and lower cost of production compared to the traditional production of cut flowers (Safeena et al., 2019). *Asparagus* is one of the ornamental plants whose cladophylls are widely grown for cut foliage usage. The Asparagaceae family has more than 210 species, occurring in the most tropical regions of the world, being South Africa, the center of its diversity (Kanno and

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Yokoyama, 2011). Plants of this genus present various forms including herbaceous perennials, woody shrubs, and vines (Kodela et al., 2021). Asparagus species, like other cut foliage, have a shorter shelf life, which is affected by pre and postharvest factors. Accordingly, in recent years, with the expansion of the worldwide production and trade of cut flowers and ornamental plants, a great deal of research has been done to extend the shelf life of these crops and have yielded favorable results for many plants (Sedaghathoor et al., 2020; Kazemi and Shokri, 2011; Kazemi et al., 2018). The quality and longevity of cut flowers are highly dependent on the pre-harvest and postharvest factors; including stresses such as increased respiration, decreased water uptake and fresh weight, changes in hydraulic conductivity and water content. Therefore, management of these factors and the application of some treatments pre and post harvesting cut flowers are essential (Sales et al., 2021; Safeena et al., 2019).

Salicylic acid (SA) is one of the growth regulators that has been widely used as a natural and effective compound on postharvest and it present great efficacy in both, pre and postharvest stages (Hassoon and Abduljabbar, 2019). Salicylic acid plays an important role in plant growth and response to various stresses such as salinity and high temperature (Sabzmeydani et al., 2020) as well as in metabolic and physiological activities (Kazemi and Shokri, 2011). Salicylic acid reduces lipid peroxidation by increasing the activity of antioxidant enzymes and maintaining the cell membrane stability, prolonging crops postharvest (Hassoon and Abduljabbar, 2019). According to Heidarnezhadian et al. (2017), application of salicylic acid on *Gerbera jamesonni* flowers lead to longer vase life by decreasing respiration rate and malondialdehyde, increasing membrane stability and enzymatic activity.

Gibberellic acid (GA) is a growth regulator that, in addition to its effects on plant growth, has received special attention in postharvest shelf life of horticultural products (Saeed et al., 2013). Also, GA prevents the breakdown of proteins by reducing the activity of the proteases. Gibberellic acid inhibits chlorophyll deterioration, prevents plant leaves chlorosis and preserves cell membrane fluidity and prevents electrolyte leakage, delaying aging and extending postharvest life (Iqbal et al., 2017). Saeed et al. (2013) found that the use of low GA concentrations in *Gladiolus* reduced the electrolyte leakage, resulting in higher activity of antioxidant enzymes and extended vase life. Since there was a lack of research that has been done on *Asparagus umbellatus* and based on the importance of postharvest management of foliage plant, this study aimed to investigate the effects of the application of salicylic acid and gibberellic acid in pre and postharvest stages.

Materials and Methods

Plant materials and treatment

The experiment was conducted in a factorial based on randomized complete block design with two factors comprising GA and SA, each of them in 4 concentrations (0, 100, 200, and 400 µM) comprising 16 treatments and 3 replications. *Asparagus umbellatus* pots were obtained from a commercial greenhouse in Amol city (in Mazandaran province) and there were grown in the same age, maturity and environmental conditions to minimize the impact of adverse factors.

In this study, the effects of plant growth regulators (GA and SA) on *Asparagus umbellatus* at two different stages (pre and postharvest) were investigated. In the pre-harvest experiment (1st test), shoots were sprayed with the desired concentrations of GA and SA (0, 100, 200 and 400 µM) during the maximum growth period and only one branch was randomly harvested from each plant at commercial maturity (about 7 inch for cuts). These asparagus cut branches were then transferred to the post-harvest laboratory in the shortest possible time, and maintained at 20-25 °C and relative humidity of 70%-75% in 200 ppm 8-hydroxyquinoline sulfate and 2% sucrose as vase solution for plant carbohydrate supply and antibacterial and strong fungicide.

In the second experiment, branches that were free of any pre-harvest treatment were harvested at the commercial maturity stage and transferred to the laboratory in the shortest time and storage in cold chamber (with 4 °C), in vase solutions containing GA and SA with the same concentrations (0, 100, 200, and 400 µM). The end of the experiment was defined as the point that 30% of the branches indicated symptoms of yellowing and drying out (Skutnik et al., 2006).

Vase life and its components measurement

At the end of the experiment, the vase life of the plant, total chlorophyll content (Mazumdar and Majumder, 2017), relative water uptake (Sedaghathoor et al., 2020), microbial accumulation (Hatamzadeh et al., 2012), electrolyte leakage, relative water content (Sedaghathoor et al., 2020), malondialdehyde content as well as the activities of catalase, superoxide dismutase and peroxidase (Mazumdar and Majumder, 2017) were investigated.

To measure chlorophyll content of leaves, different treatments were sampled. Then, 0.5 g of the sample was weighed and grounded in a Chinese mortar containing 50 mL acetone 80% (80 mL acetone + 20 mL distilled water). The extract was infiltrated, reached to 50 cc, and poured into small containers. The absorption maxima of chlorophyll *a* and chlorophyll *b* were read at 643 and 660 nm by a JASCO Model V-530 spectrophotometer. Then, the recorded figures (A) were put in the following equation to calculate total chlorophyll (Mazumdar and Majumder, 2017):

$$\text{Total chlorophyll (mg/ml)} = 7.12(\text{A}_{660}) + 16.8(A_{643})$$

To measure the relative water content of the leaves, they were weighed and their fresh weight was recorded. Then, they were oven-dried at 60 °C for 72 hours and their dry weight was recorded. The difference between the dry and fresh weight used to yield the relative water content (Sedaghathoor et al., 2020). The activity of catalase was measured through the following stages (Mazumdar and 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 H_2O_2 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 above. Then, the variations of OD were read at 430 nm with a spectrophotometer once thirty seconds for two minutes (Mazumdar and Majumder, 2017).

Statistical analysis

Data were analyzed using MSTATC statistical software (MSTAT Development Team, 1989). and mean comparisons by Duncan's Multiple Range Test at 1% probability level.

Results and Discussion

Total chlorophyll content

As Tables 1 and 2 shows, the application of gibberellic acid and salicylic acid at all concentrations (separately or in combination) was able to increase the total chlorophyll content compared to the control and lead to a significant advantage of chlorophyll content of treated foliage cuts of *Asparagus*. Means comparison for the effect of pre-harvest treatments on the total chlorophyll (Table 1) indicated that the highest total chlorophyll (2.94 mg g^{-1} FW) was related to the SA_{100}+GA_{200} and the lowest chlorophyll (2.26 mg g^{-1} FW) to SA_{400}+GA_{400} treatment.

Table 1. Mean comparison of the effect of different treatments (pre-harvest) on biochemical indices of *Asparagus umbellatus*.

Treatment	Total Chlorophyll Content (mg g^{-1} fresh weight)	MOD (mMol g^{-1} fresh weight)	CAT (units g^{-1} fresh weight)	SOD (units g^{-1} fresh weight)	POL (units g^{-1} fresh weight)
Control	1.69 j*	51.91 a	1.08 g	1.08 e	0.75 j
GA_{100}	2.49 gfe	18.63 f	3.31 ed	3.24 bc	2.17 fe
GA_{200}	2.50 fe	18.65 f	3.38 bdc	3.28 bc	2.29 e
GA_{400}	2.39 gh	22.62 c	3.15 f	3.12 d	1.38 i
SA_{100}	2.55 dce	18.10 hg	3.34 edc	3.24 bc	2.08 f
SA_{100}+GA_{100}	2.64 c	18.24 g	3.42 bac	3.33 ba	2.55 d
SA_{100}+GA_{200}	2.94 a	16.65 i	3.44 ba	3.32 ba	3.18 b
SA_{100}+GA_{400}	2.49 fe	22.26 d	3.26 e	3.10 d	1.65 h
SA_{200}	2.53 dfe	18.90 f	3.32 ed	3.29 b	2.25 e
SA_{200}+GA_{100}	2.75 b	17.80 h	3.43 bac	3.34 ba	3.01 c
SA_{200}+GA_{200}	2.62 dc	16.59 i	3.49 a	3.40 a	3.42 a
SA_{200}+GA_{400}	2.43 gfh	20.79 e	3.26 e	3.23 bc	1.83 g
SA_{400}	2.38 h	22.12 d	3.16 f	3.18 dc	1.42 i
SA_{400}+GA_{100}	2.37 h	22.88 c	3.25 e	3.13 d	1.74 hg
SA_{400}+GA_{200}	2.37 h	20.59 e	3.29 e	3.23 bc	1.87 g
SA_{400}+GA_{400}	2.26 i	23.61 b	3.13 f	3.13 d	1.45 i

*In each column, mean that have at least one common letter are in statistically similar groups with Duncan's multiple range tests at 1% possibility.

One of the benefits of GA in plants is to decrease of chlorophyll and nitrogen degradation during the senescence process, which is attributed to the structural role of gibberellic acid in the chloroplast membrane (Emamverdian et al., 2020). Also, Skutnik et al. (2006) reported that chlorophyll content remained high in asparagus shoots with GA (0.25 $mmol.dm^{-3}$). On the other hand, SA also plays an important role in increasing photosynthesis and chlorophyll content of the plant (Moustafa-Farag et al., 2020) and decreases the activity of chlorophyllase and consequently increases photosynthesis in plant. Cao et al. (2021) reported that the application of SA increased the content of chlorophylls and carotenoids in *Chrysanthemum*. According to our results, the best results were obtained in the pre-harvest spraying of SA_{100}+GA_{200} and in the post-harvesting treatment SA_{200}+GA_{200}. Results indicated that chlorophyll content under pre-harvest treating was higher than postharvest application about 12.5%. This means that the foliar application of GA and SA in the pre-harvest stage had effect on the total chlorophyll content compared to the application of these PGRs (plant growth regulators) as a vase solution. Therefore, pre-harvest spraying of GA and SA inhibited chlorophyll degradation in *Asparagus umbellatus;* chlorophyll maintenance under this pre-harvest treatment shows a 74% advantage over the control, which is a significant quantity (Tables 1 and 2).

Electrolyte leakage

Based on the results (Tables 2 and 4), the application of GA and SA resulted in less electrolyte leakage in plants compared to control treatment.

Table 2. Mean comparison of the effect of different treatments (pre-harvest) on physiological indices of *Asparagus umbellatus*

Treatment	Electrolyte Leakage (%)	Relative Water Uptake (%)	Bacterial Load (%)	Relative Water Content (%)
Control	36.68 a	51.65 j	7.36 a	60.34 k
GA_{100}	19.21 d	82.84 d	1.81 cb	81.72 de
GA_{200}	18.74 e	82.97 d	1.75 cb	81.61 de
GA_{400}	20.14 c	78.41 h	1.84 cb	74.95 hi
SA_{100}	19.14 d	82.27 e	1.77 cb	81.19 e
SA_{100}+GA_{100}	18.47 fe	83.93 cb	1.78 cb	82.22 dc
SA_{100}+GA_{200}	17.29 h	86.27 a	1.72 c	83.60 a
SA_{100}+GA_{400}	20.02 c	79.13 g	1.83 cb	75.73 g
SA_{200}	18.59 e	83.39 cd	1.78 cb	81.43 e
SA_{200}+GA_{100}	18.18 f	84.19 b	1.72 c	82.81 bc
SA_{200}+GA_{200}	17.67 g	85.88 a	1.75 cb	83.38 ba
SA_{200}+GA_{400}	19.27 d	79.93 f	1.76 cb	78.64 f
SA_{400}	20.30 cb	78.12 h	1.80 cb	73.69 j
SA_{400}+GA_{100}	20.05 c	79.22 g	1.82 cb	75.53 hg
SA_{400}+GA_{200}	19.45 d	79.87 f	1.78 cb	78.11 f
SA_{400}+GA_{400}	20.55 b	77.51 i	1.96 b	74.86 i

*In each column, mean that have at least one common letter are in statistically similar groups with Duncan's multiple range tests at 1% possibility.

Table 3. Comparison of the mean effect of different treatments (post-harvest) on the biochemical indices of *Asparagus umbellatus*

Treatment	Total Chlorophyll Content (mg g^{-1} fresh weight)	MOD (mMol g^{-1} fresh weight)	CAT (units g^{-1} fresh weight)	SOD (units g^{-1} fresh weight)	POL (units g^{-1} fresh weight)
Control	1.35 e*	53.12 a	1.30 f	1.30 h	0.81 j
GA_{100}	2.41 dc	20.78 e	3.08 dc	3.18 dc	2.14 d
GA_{200}	2.47 bac	20.08 fe	3.16 bc	3.26 bc	2.24 d
GA_{400}	2.37 dc	23.67 c	3.09 dc	3.05 f	1.34 i
SA_{100}	2.46 bac	20.89 e	3.13 c	3.13 dfe	2.00 e
SA_{100}+GA_{100}	2.55 ba	19.64 fg	3.23 ba	3.31 ba	2.52 c
SA_{100}+GA_{200}	2.56 ba	18.97 g	3.26 a	3.33 ba	3.25 a
SA_{100}+GA_{400}	2.41 dc	22.39 d	3.11 dc	3.07 fe	1.59 hg
SA_{200}	2.49 bac	20.44 fe	3.15 bc	3.20 dc	2.23 d
SA_{200}+GA_{100}	2.56 ba	19.50 fg	3.30 a	3.40 a	3.27 a
SA_{200}+GA_{200}	2.57 a	18.73 g	3.31 a	3.34 ba	3.12 b
SA_{200}+GA_{400}	2.43 bdc	22.28 d	3.13 c	3.16 dce	1.81 f
SA_{400}	2.35 dc	23.66 c	3.02 de	3.11 dfe	1.39 i
SA_{400}+GA_{100}	2.36 dc	23.16 dc	3.09 dc	3.04 f	1.67 g
SA_{400}+GA_{200}	2.42 bdc	22.18 d	3.13 c	3.15 de	1.83 f
SA_{400}+GA_{400}	2.31 d	24.71 b	2.96 e	2.84 g	1.50 h

*In each column, means that have at least one common letter are in statistically similar groups with Duncan's multiple range tests at 1% possibility.

Table 4. Comparison of the mean effect of different treatments (post-harvest) on the physiological indices of *Asparagus umbellatus*

Treatment	Electrolyte Leakage (%)	Relative Water Uptake (%)	Bacterial Load (%)	Relative Water Content (%)
Control	37.23 a	49.08 i	7.70 a	60.67 i
GA_{100}	21.41 f	78.96 d	2.05 de	76.76 ed
GA_{200}	20.01 g	80.80 c	2.04 de	78.11 c
GA_{400}	22.92 c	75.39 h	2.14 c	73.34 h
SA_{100}	21.27 f	79.04 d	2.01 e	77.23 d
SA_{100}+GA_{100}	19.80 g	81.67 b	2.00 e	79.27 b
SA_{100}+GA_{200}	19.02 i	82.46 a	2.03 de	79.31 b
SA_{100}+GA_{400}	22.49 d	76.85 f	2.14 c	73.76 hg
SA_{200}	19.81 g	80.98 c	2.03 e	78.26 c
SA_{200}+GA_{100}	18.95 i	82.91 a	1.91 f	79.95 ba
SA_{200}+GA_{200}	19.31 h	82.76 a	1.91 f	80.68 a
SA_{200}+GA_{400}	21.95 e	77.40 fe	2.08 dce	75.92 f
SA_{400}	22.98 cb	75.96 g	2.16 c	73.87 hg
SA_{400}+GA_{100}	22.43 d	77.15 fe	2.12 dc	74.22 g
SA_{400}+GA_{200}	22.48 d	77.49 e	2.08 dce	76.12 ef
SA_{400}+GA_{400}	23.22 b	75.11 h	2.28 b	73.15 h

*In each column, means that have at least one common letter are in statistically similar groups with Duncan's multiple range tests at 1% possibility.

Reduced electrolyte leakage indicates better cellular membrane stability and integrity (Sedaghathoor et al., 2020). Therefore, the applied treatments have been able to decrease leakage by reducing lipid peroxidation and maintaining membrane health. Reduction of electrolyte leakage helps to sustain plant vase life. The reason can be attributed to the preservation of cell membrane fluidity and the prevention of electrolyte leakage due to GA application (Iqbal et al., 2017). Based on this, Singh et al. (2008) reported that the application of gibberellic acid pre and post harvesting in gladiolus cut flower could increase the vase life by increasing the cell membrane stability.

The application of salicylic acid can also decrease lipid peroxidation by increasing the activity of antioxidant enzymes, thereby prolonging plant longevity (Moustafa-Farag et al., 2020). The effect of salicylic acid in reduction of lipid peroxidation and increasing membrane stability has been reported by Hatamzadeh et al. (2012). The lowest amount of electrolyte leakage (17.29%) was observed under the SA_{100}+GA_{200} treatment for the first experiment (pre–harvest treated shoots) and the SA_{100}+GA_{200} (19.02%) and SA_{200}+GA_{100} (18.95%) treatments for the second experiment (postharvest test) (Tables 2 and 4). Therefore, pre and postharvest foliar application of GA and SA showed lower electrolyte leakage in the plant; but, pre-harvest application was more effective. The highest electrolyte leakage was observed under control at both pre-harvest (36.68%) and postharvest (37.23%) experiments.

Relative water uptake

Pre and post-harvest application of GA and SA promoted higher relative water uptake compared to the control (Table 2 and 4). One of the reasons of the cut flowers withering is the decline in relative water uptake, which is directly related to the blockage of the stem.

The application of GA and SA lead to significantly high relative water uptake for the plant. One of the functions of GA is to hydrolyze complex carbohydrates into monosaccharides which results in lower osmotic potential and then the cell uptakes more water. Therefore, the application of these treatments as a foliar solution and a preservative solution results in higher relative uptake of the solution as well as the relative water content and relative fresh weight of the cut flowers (Mutui et al., 2003). SA, on the other hand, can improve the aqueous relationships and relative solubility of the plant by maintaining cellular turgidity. Kazemi et al. (2018) suggest that the longevity of cut flowers of rose with the application of SA (at pre and postharvest stages) is associated to a significant increase in relative water uptake, relative fresh weight, and antioxidant enzyme activity. Kazemi et al. (2011) found that the application of SA with other chemicals in preservative solution of *Gerbera* reduces the microbial population and increases the water uptake.

The SA_{100}+GA_{200} (86.27%) and SA_{200}+GA_{200} (85.88%) treatments in the pre-harvest stage and these two treatments plus the SA_{200}+GA_{100} (82.91%) and SA_{200}+GA_{200} (82.76%)

treatments in the post-harvest stage were able to obtain the highest relative water uptake in *Asparagus umbellatus.*

Microbial population

Tables 2 and 4 showed both GA and SA reduced the microbial population of cut branches of *Asparagus umbellatus*. The results of Singh et al. (2008) indicate that the application of GA can reduce the peroxidation of membrane lipids in the *Gladiolus* and improved cell wall stability, besides reducing microbial population. In addition to the stem blockage, microbes produced in the vase solution causes cell death and decrease quality in cut flowers (Nguyen and Lim, 2021). Therefore, the application of GA and SA has been able to significantly control the population of microbes in both experiments.

Improved vase life of *Asparagus* cut shoots treated with SA can largely be attributed to the bactericidal activity of SA. SA lead to prevent of stem blockage by microorganisms, which eventually causes increases in water holding capacity in *Vica* branches (Mori et al., 2001). Hatamzadeh et al. (2012) also showed that SA application in *Gladiolus* was associated with reduced microbial population and occlusion of xylem. As the results showed, no significant effect was observed between pre-harvest GA and SA treatments, but in postharvest stage, the application of 200μM SA + 100 and 200 μM of GA allowed the lowest microbial population values.

Based on the results, it is clear that the pre-harvest application of GA and SA resulted in lower amounts of microbial population (1.72%) than postharvest treatments (1.91%).

Relative water content

GA and SA were able to significantly increase relative water content in *Asparagus umbellatus* in both experiments (Tables 2 and 4). GA increased cell wall permeability and then due to concentrating the sap, the cell water potential reduces, resulting in improved relative water content (Emamverdian et al., 2020).

SA also increased relative water content and plant growth by increasing cell-soluble osmolytes such as proline. The osmolytes production leads to facilitate osmotic adjustment, by which the internal osmotic potential is lower and may contribute to tolerance (Hasegawa et al., 2000).

Based on the results of this experiment, the highest relative water content was observed in a pre-harvested foliar application of SA_{100}+GA_{200} (83.60%) and post-harvest experiment in SA_{200}+GA_{200} treatment (80.68%). Although both, pre and post-harvest treatments, improved the relative water content of the plant compared to control, the highest relative water content was obtained by using GA and SA in the pre-harvest stage. Thus, *Asparagus umbellatus* showed a better response to GA and SA in the pre-harvest stage.

Malondialdehyde (MDA) content

The content of MDA was significantly reduced by the GA and SA treatments (Tables 1 and 3). MDA is a type of aldehyde compound that results from the peroxidation of cell membrane lipids. Detection of MDA has traditionally been used as a main indicator of lipid peroxidation. As one of secondary products of lipid peroxidation, MDA can be used as a marker of cell membrane injury (Liu et al., 2020). According to the results, the increase trend of electrolyte leakage and accumulation of malondialdehyde, along with lipoxygenase activity, was significantly slower than in the branches treated with GA and SA, leading to the maintenance of membrane integrity. Therefore, pre and post-harvest treatment with GA and SA resulted in a decrease in electrolyte leakage and accumulation of malondialdehyde and also delayed senescence of *Asparagus* cut foliage. In a studies developed by Singh et al. (2008) on *Gladiolus* cut flower and Bahrami et al. (2013) on *Lisianthus* cut flower, were observed the reduction of MDA and increase of vase life under GA and SA treatment, respectively. According to the results of present study, the combination of SA_{100} and SA_{200} + GA_{200} in both experiments produced the lowest MDA content, but MDA content was lower in pre-harvest treatment. The lowest MDA content in pre-harvest test was obtained from SA_{100}+GA_{200} (16.65 mMol g^{-1} FW) and SA_{200}+GA_{200} (16.59 mMol g^{-1} FW) showing insignificant differences from other treatments (Table 2).

Antioxidant enzymes activity

The results showed that the antioxidant enzymes including catalase (CAT), superoxide dismutase (SOD) and peroxidase (POL) activity in *Asparagus umbellatus* increased with the application of GA and SA (Tables 1 and 3). Since lipid peroxidation in plant cell membranes is affected by reactive oxygen species, increasing in activity of the antioxidant enzymes by application of GA and SA at pre-harvest and post-harvest stages has been studied. These enzymes can neutralize reactive oxygen species and reduce membrane lipid peroxidation and electrolyte leakage, improving vase life of cut branches of *Asparagus umbellatus*. Accordingly, the results of Singh et al. (2008) showed that treatment of GA on the buds of *Gladiolus* could decrease the peroxidation of lipids and increase the activity of antioxidant enzymes and the vase life of this cut flower. Also Moustafa-Farag et al. (2020) reported that SA can reduce the damage caused by oxidative stress in rose and delay plant senescence. In the pre-harvest experiment testing GA and SA, the highest activity for all enzymes was observed in SA_{200}+GA_{200} treatment. Whereas in the second experiment (postharvest test), the highest amount of CAT, SOD and POL enzymes belonged to SA_{200}+GA_{100} treatment. According to Tables 1 and 3, the application of all concentrations of GA and SA in both experiments lead to improved results than control plants, but the highest enzymatic activity, relative water uptake and relative water content, as well as the lowest electrolyte leakage, microbial population and MDA content observed in combinations of the 100 to 200 μm of GA and SA. Although all GA and SA treatments were superior to the control; however, among the SA and GA treatments, the simple effects of high concentrations of these compounds (400 μM) were less effective than low concentrations (100 and 200 μM). The effect of application of GA and SA in the pre and

postharvest stage on the activity of antioxidant enzymes was almost the same.

Vase life

According to Figures 1 and 2, the application of GA and SA in pre and post-harvest stages at all concentrations increased significantly the vase life of *Asparagus umbellatus* compared to the control. Vase life difference between control (9.34 days) and the superior treatment i.e. GA_{200}+SA_{200} (14.07 days) was more than 50%. This difference in postharvest industry is important and impressive.

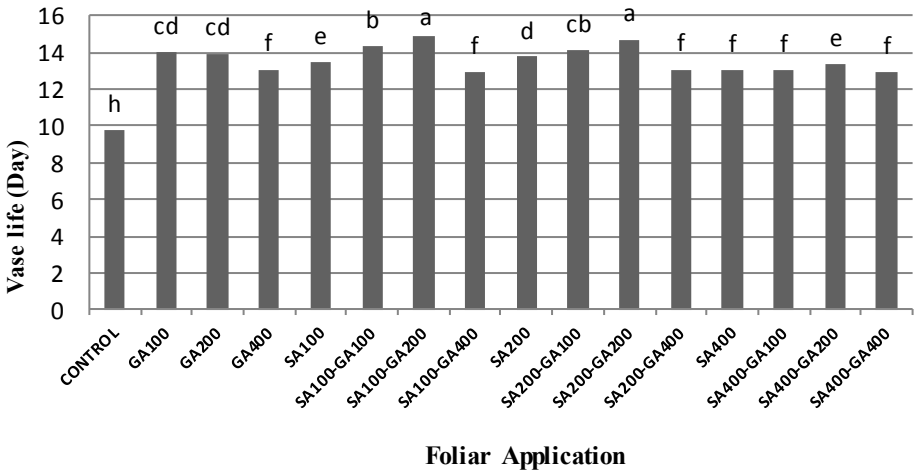

Figure 1. The effect of foliar application of different treatments on the vase life of *Asparagus umbellatus.*

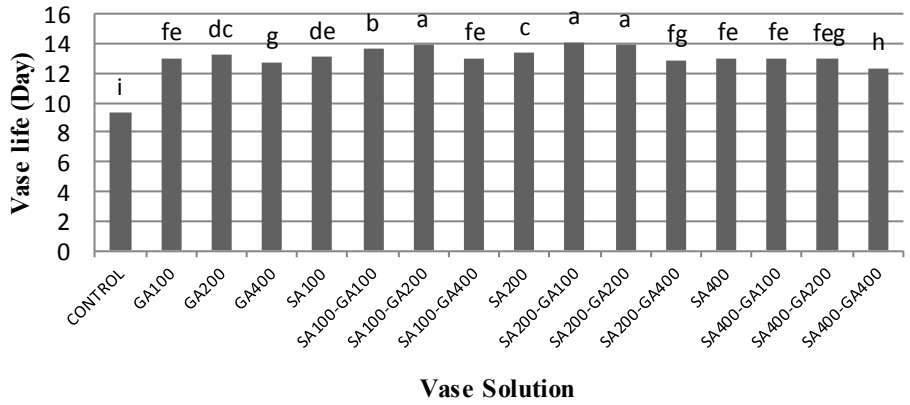

Figure 2. The effect of different treatments as a vase solution on the vase life of *Asparagus umbellatus.*

According to Figures 1 and 2, the longest vase life in the per-harvest experiment (spraying with GA and SA in pre-harvest stage) was obtained using SA_{100}+GA_{100} and SA_{200}+GA_{200} treatments with 14.89 and 14.67 days, respectively. In the second experiment (GA and SA as a vase solution) the longest vase life were obtained with the application of SA_{100}+GA_{200}, SA_{200}+GA_{100}, and SA_{200}+GA_{200} being 13.93, 14.07 and 13.93 days, respectively. As mentioned in the preceding traits, the combination of 100 and 200 µM concentrations of these PGRs yielded the best results, resulting in the longest vase life at *Asparagus umbellatus*. Therefore, based on the results, it can be stated that the application of these two PGRs can be applied as a foliar application in pre-harvest or preservative solution at the post-harvest stage can provide the longest vase life for *Asparagus*.

Increasing the vase life of cut flowers and their quality can have a huge impact on the sale of these products and senescence of the cut flowers can greatly impair their quality. Therefore, factors that delay the onset of symptoms in these products should be identified and strategies developed. Much attention has been paid to the materials in recent years in the field of post-harvest science such as GA and SA which have very beneficial effects on the growth, quality and shelf life of crops pre and postharvest.

Conclusions

The separate and combined application of GA and SA in pre-harvest and post-harvest stages had a favorable effect on the *Asparagus umbellatus* and improved the senescence indices associated with plant growth. Therefore, the

combination of GA and SA in the range of 100 to 200µm can be suggested to enhance the quality and vase life in *Asparagus umbellatus*. The use of high concentrations of GA and SA (400 µM) is not recommended due to the negative effect on vase life and high cost.

Author Contribution

MA, RN, SS, SK: study conception and design. **MA:** acquisition of data. **MA, SS:** analysis and interpretation of data. **MA, RN, SS, SK.:** drafting of manuscript.

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