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The Improvement of Postharvest Longevity of Cut *Alstroemeria* 'Konst Coco' Flowers by a Combination of Mechanical and Chemical Methods

Mehdi Hakimi Asl[1] and Ahmadreza Berimavandi[2*]

[1]Former Student, Department of Horticultural Science, Rasht Branch, Islamic Azad University, Rasht, Iran
[2*]Department of Agronomy, Islamic Azad University, Rasht Branch, Rasht, Iran

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*Corresponding author's email: a_r_berimavandi@yahoo.com

Abstract

The interactive effect of mechanical methods (stem-end splitting) and chemical methods (silver nanoparticles) was studied on the vase life and biochemical characteristics of cut *Alstroemeria* cv. 'Konst Coco' flowers in a factorial experiment based on a completely randomized design with 10 treatments, 3 replications, 30 plots, and 150 flowers. The experimental treatments included longitudinal stem-end split at two levels (no split and a 5-cm split) and silver nanoparticles (SNP) at five levels (0, 5, 10, 20, and 30 mg L^{-1}). The results showed that the interaction of the experimental treatments was statistically significant for all recorded traits. Based on the results, the longest vase life (13.88 days) was obtained from the application of "5 cm split × 20 mg L^{-1} SNP", showing a 6.83 day increase versus the control. The treatment of "5 cm split × 20 mg L^{-1} SNP" recorded the highest water uptake (2.03 ml g^{-1} F.W.), dry matter (14.11%), total chlorophyll (2.432 mg g^{-1} F.W.), and petal carotenoid (2.307 µg g^{-1} F.W.) and the lowest fresh weight loss (1.34 g), stem-end and vase solution bacteria (3 Log_{10} CFU mL^{-1}), ethylene synthesis (0.807 nl l^{-1} h^{-1} g^{-1} F.W.), electrolyte leakage (6.04 %), MDA (12.53 nmol g^{-1} F.W. min^{-1}), SOD activity (12.64 IU g^{-1} F.W. min^{-1}), and POD activity (0.009 nmol g^{-1} F.W. min^{-1}), so it was the best treatment in preserving vase life and biochemical properties of the cut *Alstroemeria* 'Konst Coco' flowers.

Keywords: Antioxidant enzymes, Ethylene, Membrane peroxidation, Silver nanoparticles, Stem-end split.

INTRODUCTION

The shelf life of cut flowers is one of the most important criteria for their selection by consumers. Most cut flowers have short shelf lives. *Alstroemeria* is a famous cut flower from the family of Alstroemeriaceae. The vase life of this cut flower is mainly limited by the yellowing and early shedding of its leaves caused by ethylene sensitivity and vascular blockage due to the activity of microorganisms. Therefore, for viable export of this cut flower, optimal conditions should be provided to extend its vase life (Ershad Langerodi *et al*., 2020; Anvari *et al*., 2022).

Vase solutions, which supply water and food for the stems cut from their maternal plants, have a special place in postharvest science. Sucrose or any other sugar source, water, and disinfectants are the main compounds in vase solutions. Silver nanoparticles (SNP) are used as a disinfectant and anti-ethylene compound in the vase solutions of many cut flowers, and their positive effect has been reported (Anvari *et al*., 2022; Ershad Langroudi *et al*., 2020; Jowkar *et al*., 2013). SNP negatively influences a wide range of microorganisms and is a strong disinfectant to control the microbial colonies of stem ends and vase solutions. In addition to its disinfectant effect, SNP provides ideal conditions for the survival of cut flowers by reducing ethylene synthesis, preventing the synthesis of free oxygen radicals, and hindering oxidative stress (Solgi and Ghorbanpour, 2015; Ershad Langroudi *et al*., 2020; Naing and Kim, 2020).

Mechanical methods, e.g., removing the bark of the stem end or splitting the stem end, are used to increase water uptake and improve the freshness of cut flowers. Presumably, these mechanical methods extend postharvest longevity by increasing the contact area of the vessels with the vase solution, enhancing water and sucrose uptake, and preserving cell turgor. However, it is necessary to treat the split stems with disinfectants to control the growth of microorganisms (Ahmad *et al*., 2011; Dashtbany and Hashemabadi, 2015). Ahmad *et al*. (2011) stated that applying two 5-cm splits to the stem end of roses and acacia increased their vase life by 1.8 and 0.2 days versus the control (non-split stem ends), respectively. In Dashtbany and Hashemabadi's (2015) study, the application of "a 5-cm split of stem end + 10% geranium essential oil" enhanced water uptake and extended the vase life of cut chrysanthemum flowers. Similarly, Sadeghi Hafshejani and Hashemabadi (2016) reported that "a 5-cm split + ethanol disinfectant" increased vase solution uptake, pigments, and vase life of *Alstroemeria*.

Given the positive effect of the stem-end split along with disinfectants on the vase life of cut flowers, this research aimed to investigate the interactive effect of "stem-end split × SNP" on the vase life, ethylene synthesis, and antioxidant activity of cut *Alstroemeria* 'Konst Coco' flowers.

MATERIALS AND METHODS

Plant materials and experimental site conditions

The cut Alstroemeria 'Konst Coco' flowers were purchased at the semi-bloom step at a commercial greenhouse in Isfahan province and were immediately transferred to the study site in commercial packages. The flowers were the same size and with no symptoms of pests, diseases, or mechanical defects. Before the experiment, the flowers were divided into five-flower bundles and were cut into a height of 55 cm. Then, their fresh weight was recorded with a digital scale. Before the treatments were applied, the flower stems were re-cut under tap water to avoid vascular blockage. The experiment was conducted in a controlled environment with 12 hours of light conditions with a light intensity of 12 µmol m^2 s^{-1}, relative humidity of 60-70%, and a temperature of 20 ± 2°C.

Experimental design and treatments

The study was conducted as a factorial experiment based on a completely randomized design with 10 treatments, 3 replications, 30 plots, and 5 flowers per plot. The experimental treatments included a longitudinal split of the stem end (S) at two levels of no split (S_0) and a 5-cm split (S_5) (Fig. 1) and the pulse treatment (24 hours) of SNP at five levels of 0 (SNP_0), 5 (SNP_5), 10 (SNP_{10}), 20 (SNP_{20}), and 30 mg/L (SNP_{30}), applied in combination.

Fig. 1. The 5 cm split at the stem end of *Alstroemeria*.

Measurement of traits

The vase life of the cut *Alstro*emeria flowers was measured as the count of days from the application of the treatments to the visual observation of 50% petal withering and leaf yellowing (Mutui *et al*., 2006) (Fig. 2).

Fig. 2. The end of the vase life of the cut *Alstroemeria* flowers.

Water uptake and fresh weight loss were determined by equations (1) and (2), respectively. After the flowers were dried at 75°C for 24 hours, they were weighed with a 0.001-g digital scale.

$$\text{Solution uptake (ml/g F.W.)} = \frac{V_{t0} - (E_t + V_{t1})}{\text{F.W.}} \qquad (1)$$

In which V_{t0} is the initial volume of the vase solution, E_t is the mean evaporation from the solution surface, V_{t1} is the volume of the solution remained on the last day, and F.W. is the flowers' fresh weight on day 1.

Fresh weight loss (g) = Initial fresh weight – (Final fresh weight + Recut weight + Desiccants weight) (2)

Vase solution and stem-end bacteria were counted by Liu *et al*.'s (2009) method, electrolyte leakage was measured by Kaya *et al*.'s (2001) method, chlorophyll a, b, total, and carotenoid contents of the petals were measured by Mazumdar and Majumder's (2003) procedure, and ethylene, malondialdehyde, superoxide dismutase activity, and peroxidase were measured by the procedures described by Alizadeh Matak *et al*. (2017), Heath and Parker (1968), In *et al*. (2007), and Giannopolitis and Ries (1997), respectively.

Data analysis

The recorded data were analyzed using the SAS statistical software package, and the means were compared by the LSD test at the $P < 0.01$ and $P < 0.05$ levels.

RESULTS

Table 1 presents the results of the variance analysis. According to the results, the interactive effect of the experimental treatments (stem-end split × SNP) was significant on vase life, water uptake, fresh weight loss, and electrolyte leakage at the $P < 0.05$ level and dry weight, stem-end and vase solution bacterial population, chlorophyll a, b, and total, petal carotenoid, ethylene synthesis, malondialdehyde content, and superoxide dismutase and peroxidase activity at the $P < 0.01$ level (Table 1).

Vase life

The comparison of means revealed that the shortest vase life (7.05 days) was related to the control ($S_0 \times SNP_0$). The stem-end split alone and with no SNP application ($S_5 \times SNP_0$) extended the vase life by 3.99 days versus the control. SNP at the rates of 5, 10, 20, and 30 mg/L at both levels of stem-end split prolonged vase solution, and its interaction with the 5-cm split was more effective in increasing the vase life. The longest vase life was recorded by $S_5 \times SNP_{20}$ (13.88 days) and $S_5 \times SNP_{10}$ (13.04 days). The application of SNP at the rate of 30 mg/L at both stem-end split levels reduced the vase life compared to the lower levels of SNP, showing the toxic effect of high SNP levels on the biochemical processes and vase life of *Alstroemeria* (Fig. 3).

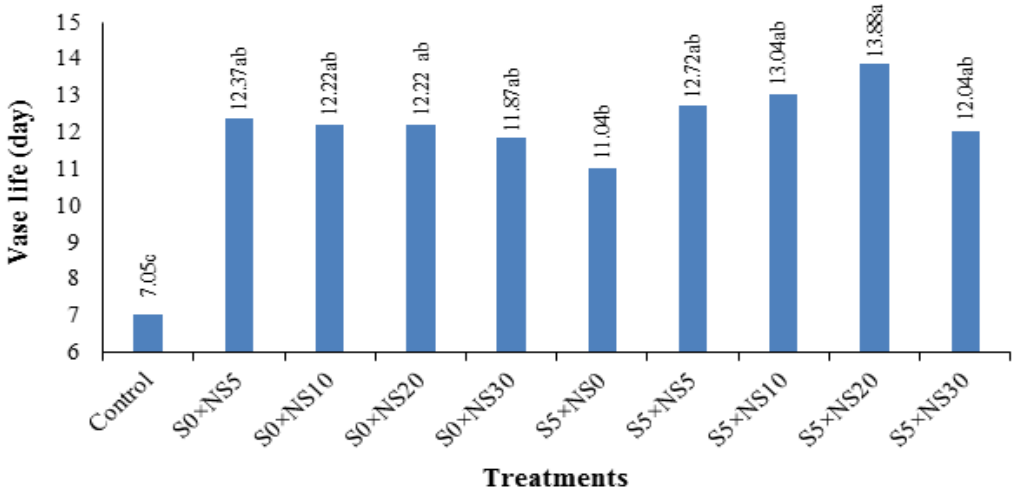

Fig. 3. The interactive effect of "stem-end split (S) × silver nanoparticles (SNP)" on the vase life of the cut *Alstroemeria* flowers.

Table 1. ANOVA for the effect of different treatments on the measured traits.

S.o.V	df	Vase life	Water uptake	Fresh weight loss	Dry weight	Bacterial population at vase solution	Bacterial population at stem end	Chlorophyll a	Chlorophyll b	Total chlorophyll
Stem-end split (S)	1	10.7*	0.106^{ns}	32.07**	0.774^{ns}	290^{ns}	76.80^{ns}	0.015*	0.0031^{ns}	0.030^{ns}
Silver nanoparticle (SNP)	4	12.77**	0.165*	15.08*	8.123**	5796**	7495**	0.057**	0.047**	0.208**
S × SNP	4	7.518*	0.216*	12.11*	9.358**	1955**	2528**	0.013**	0.031**	0.086**
Error	20	1.82	0.075	3.85	0.885	126	237	0.0026	0.0032	0.0074
CV (%)		11.41	19.38	52.17	8.6	39.21	33.03	4.02	6.33	3.96

*, ** and ^{ns}: Significant at $P < 0.05$, $P < 0.01$ and insignificant based on the LSD test, respectively.

Table 1. Continued.

S.o.V	df	Petals carotenoids	Electrolyte leakage	Ethylene production	Malondialdehyde (MDA)	Superoxide dismutase Activity (SOD)	Peroxidase activity (POD)
Stem end split (S)	1	0.460**	48.18**	0.269**	34.9**	31.08**	0.000012^{ns}
Nanosilver (SNP)	4	1.377**	4.47^{ns}	0.117**	57.66**	45.46**	0.000194**
S × SNP	4	0.383**	13.11*	0.137**	49.65**	75.04**	0.00036**
Error	20	0.015	3.89	0.0034	1.692	1.3	0.0000214
CV (%)		7.52	23.04	6.14	8.06	6.97	26.35

*, ** and ns: Significant at $P < 0.05$, $P < 0.01$ and insignificant based on the LSD test, respectively.

Table 2. Means comparison for the effect of 'stem-end split × silver nanoparticle' on the measured traits.

Treatments	Water uptake (ml g^{-1} F.W.)	Fresh weight loss (g)	Dry weight (g)	Bacterial population at vase solution (Log$_{10}$ CFU ml^{-1})	Bacterial population at stem end (Log$_{10}$ CFU ml^{-1})	Chlorophyll a (mg g^{-1} F.W.)	Chlorophyll b (mg g^{-1} F.W.)	Total chlorophyll (mg g^{-1} F.W.)	Petals carotenoids (µg g^{-1} F.W.)
$S_0 \times SNP_0$	1.153^{bc}	9.49^{a}	9.03^{d}	118^{a}	132.00^{a}	1.028^{d}	0.660^{f}	1.689^{d}	1.020^{e}
$S_0 \times SNP_5$	1.376^{b}	2.56^{bc}	10.92^{bc}	6.66^{d}	28.33^{d-g}	1.330^{ab}	0.871^{cde}	2.201^{b}	1.629^{d}
$S_0 \times SNP_{10}$	1.326^{b}	3.10^{bc}	10.38^{bcd}	6.33^{d}	49.33^{cde}	1.326^{ab}	0.982^{ab}	2.308^{ab}	1.940^{c}
$S_0 \times SNP_{20}$	1.326^{b}	3.68^{bc}	10.21^{bcd}	27.66^{c}	51.00^{cd}	1.325^{ab}	0.978^{ab}	2.303^{ab}	1.968^{bc}
$S_0 \times SNP_{30}$	1.303^{b}	3.91^{bc}	9.78^{bcd}	34.00^{bc}	58.33^{bc}	1.196^{c}	0.819^{e}	2.015^{c}	1.097^{e}
$S_5 \times SNP_0$	1.233^{b}	5.23^{b}	9.51^{cd}	47.66^{b}	83.00^{b}	1.168^{c}	0.835^{de}	2.021^{c}	1.039^{e}
$S_5 \times SNP_5$	1.543^{b}	2.48^{bc}	11.34^{b}	5.00^{d}	23.67^{efg}	1.330^{ab}	0.923^{bcd}	2.253^{b}	2.184^{a}
$S_5 \times SNP_{10}$	1.516^{b}	2.14^{bc}	13.28^{a}	4.33^{d}	7.67^{fg}	1.357^{a}	0.879^{cde}	2.237^{b}	2.162^{ab}
$S_5 \times SNP_{20}$	2.030^{a}	1.34^{c}	14.11^{a}	3.00^{d}	3.00^{g}	1.362^{a}	1.040^{a}	2.432^{a}	2.307^{a}
$S_5 \times SNP_{30}$	1.320^{b}	3.68^{bc}	10.79^{bc}	33^{bc}	30.00^{def}	1.268^{bc}	0.963^{abc}	2.256^{b}	1.140^{e}

*In each column, means with similar letter(s) are not significantly different ($P < 0.05$) using the LSD test. S_0: no stem-end split, S_5: 5-cm stem-end split; $SNP_{0,\ 5,\ 10,\ 20,\ and\ 30}$: 0, 5, 10, 20, and 30 mg/l of silver nanoparticles.

Water uptake

The interaction of "stem-end split × SNP" increased water uptake versus the control (1.153 ml g^{-1} F.W.). Stems whose ends were split by 5 cm took up more water at all five levels of SNP compared to non-split stems. The treatment of $S_5 \times SNP_{20}$ recorded the highest water uptake (2.03 ml g^{-1} F.W.) among all treatments (Table 2).

Fresh weight loss

The fresh weight loss was the highest in the control (9.49 g). Splitting the stem end by 5 cm exhibited a fresh weight loss of 5.23 g, which was greater than that of the control. The interaction of "5-cm stem-end split × SNP" was more effective than "no stem-end split × SNP" in preserving fresh weight. The lowest fresh weight loss was recorded by the treatments of $S_5 \times SNP_{20}$ (1.34 g) and $S_5 \times SNP_{10}$ (2.14 g), respectively (Table 2).

Dry weight

Based on the comparison of means, the control and $S_5 \times SNP_0$ had the first and second lowest dry weight, respectively. The application of SNP without splitting the stem end increased the dry weight versus the control, but when a 5-cm split was made in the stem end and different levels of SNP were applied, more increase was observed in the dry weight. The highest dry weight was obtained from the stems treated with $S_5 \times SNP_{20}$ (14.11 g) and $S_5 \times SNP_{10}$ (13.28 g), so they were the most successful treatments in increasing the dry weight (Table 2).

Vase solution and stem-end bacterial population

As the comparison of means revealed, the application of SNP significantly reduced the microbial load of the vase solution and stem end versus the control at both stem-end split levels. However, making 5-cm splits in the stem end further reduced the bacterial load of the vase solution and stem end at all five levels of SNP. The best treatment for reducing the microbial load was $S_5 \times SNP_{20}$, as it recorded the lowest bacterial colony. The highest vase solution and stem-end bacterial populations were recorded by the control at the first rank and $S_5 \times SNP_0$ at the second rank (Table 2).

Chlorophyll a, b, and total

Chlorophyll a, b, and total contents were increased by "stem-end split × SNP" versus the control, which exhibited the lowest chlorophyll a (10.28 mg g^{-1} F.W.), chlorophyll b (0.660 mg g^{-1} F.W.), and total chlorophyll (1.689 mg g^{-1} F.W.). The branches treated with $S_5 \times SNP_{20}$ had the highest chlorophyll a (1.362 mg g^{-1} F.W.), chlorophyll b (1.040 mg g^{-1} F.W.), and total chlorophyll (2.432 mg g^{-1} F.W.). This treatment performed the best in preserving chlorophyll pigments in the *Alstroemeria* leaves

Petal carotenoids

The application of SNP at a rate of 5, 10, 20, or 30 mg L^{-1} increased the petal carotenoids content compared to the control whose carotenoid content was 1.02 µg g^{-1} F.W. irrespective of splitting the stem end. However, the highest petal carotenoid content was 2.307 µg g^{-1} F.W. recorded by the treatment of $S_5 \times SNP_{20}$. Nonetheless, the SNP rate of 30 mg L^{-1} had a negative effect on preserving the petal carotenoid at both levels of stem-end splitting versus the SNP rates of 5, 10, and 20 mg L^{-1} (Table 2).

Ethylene

Fig. 4 shows that the control and $S_5 \times SNP_0$ exhibited the highest rate of ethylene synthesis (1.092 and 10.47 nl l^{-1} h^{-1} g^{-1} F.W., respectively). With the application of SNP and the split of the stem end, the ethylene synthesis was suppressed. The lowest rates of ethylene synthesis were 0.807 and 0.831 nl l^{-1} h^{-1} g^{-1} F.W. for the treatments of $S_5 \times SNP_{20}$ and $S_5 \times SNP_{10}$, respectively (Fig. 4).

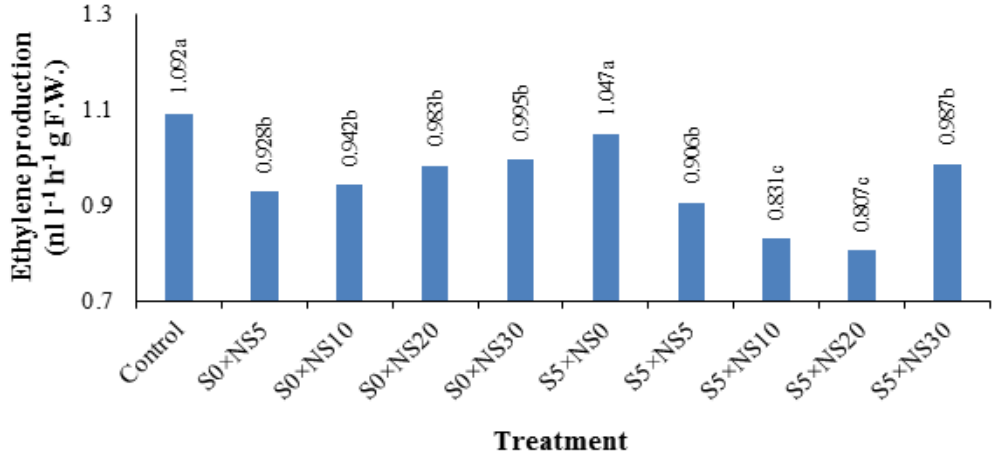

Fig. 4. The interactive effect of "stem-end split (S) × silver nanoparticles (SNP)" on the ethylene synthesis by the cut *Alstroemeria* flowers.

Electrolyte leakage

The comparison of means revealed that the electrolyte leakage was decreased by 12.35 percent with the application of "SNP × splitting" versus the control. $S_5 \times SNP_0$ reduced electrolyte leakage (11.64%) compared to the control, but their difference was not statistically significant. $S_5 \times SNP_{20}$ and $S_5 \times SNP_{10}$ were found to be the best treatments for the reduction of electrolyte leakage. They showed the lowest electrolyte leakages of 6.04 and 6.42 percent, respectively (Fig. 5).

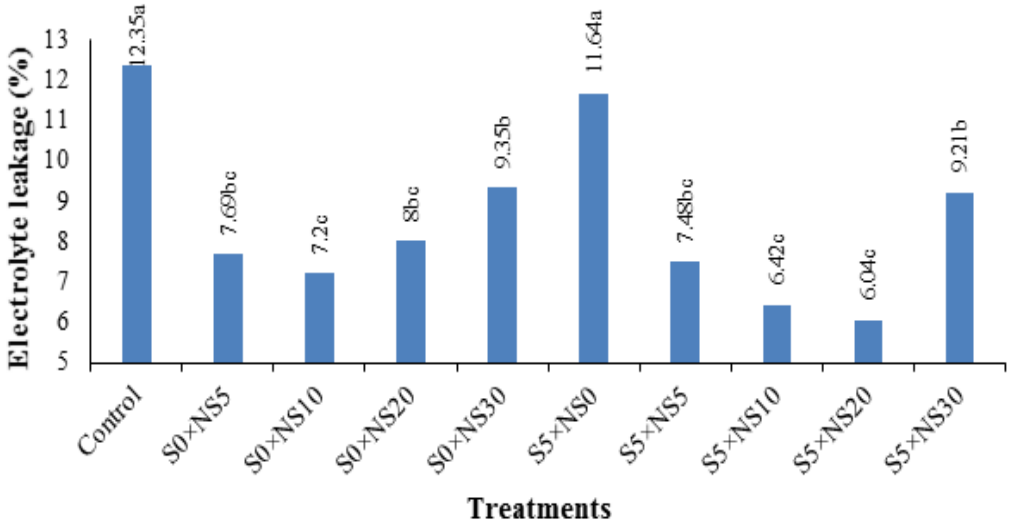

Fig. 5. The interactive effect of "stem-end split (S) × silver nanoparticles (SNP)" on the electrolyte leakage of the cut *Alstroemeria* flowers.

Malondialdehyde (MDA) content

It was found by the comparison of means that at both stem-end splitting levels, SNP decreased the MDA content versus the control (19.57 nmol g^{-1} F.W. min^{-1}). However, there was not a statistically significant difference between the control and $S_5 \times SNP_0$, which had the first and second-highest MDA contents, respectively. The lowest MDA contents were 12.53 and 13.75 nmol g^{-1} F.W. min^{-1} recorded by $S_5 \times SNP_{20}$ and $S_5 \times SNP_{10}$, respectively. At both splitting levels, the application of 30 mg/L SNP had a negative effect on MDA and increased it compared to the SNP rates of 5, 10, and 20 mg L^{-1} (Fig. 6).

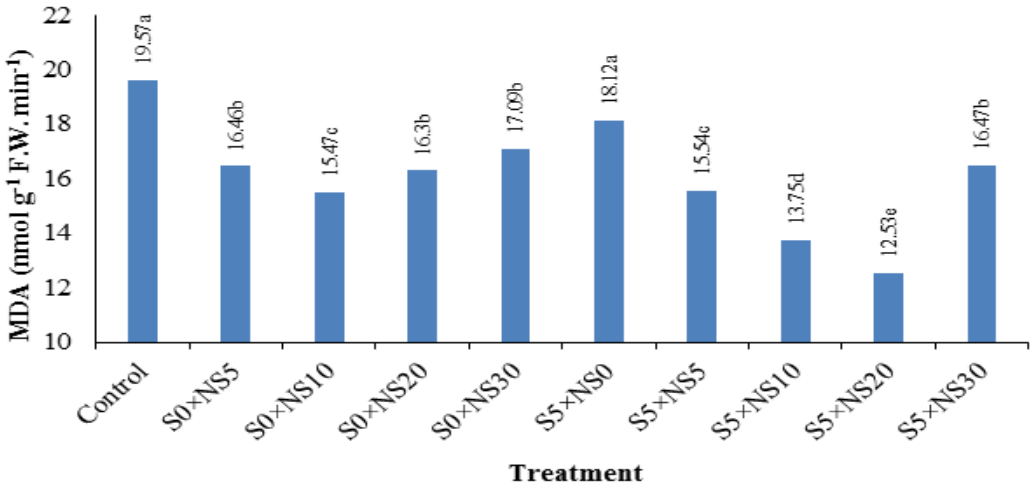

Fig. 6. The interactive effect of "stem-end split (S) × silver nanoparticles (SNP)" on MDA accumulation in the cut *Alstroemeria* flowers.

Superoxide dismutase (SOD) and peroxidase (POD) activity

Figs. 7 and 8 depict that the SOD and POD activities were decreased with the application of SNP at both splitting levels versus the control. The highest activities were related to the control and $S_5 \times SNP_0$, respectively. According to the comparison of means, the two treatments of $S_5 \times SNP_{20}$ (12.64 IU g^{-1} F.W. min^{-1}) and $S_5 \times SNP_{10}$ (12.72 IU g^{-1} F.W. min^{-1}) had the lowest SOD activity. They did not differ from one another significantly. The lowest POD activity was 0.009 nmol g^{-1} F.W. min^{-1} related to $S_5 \times SNP_{20}$ (Fig. 7 and 8).

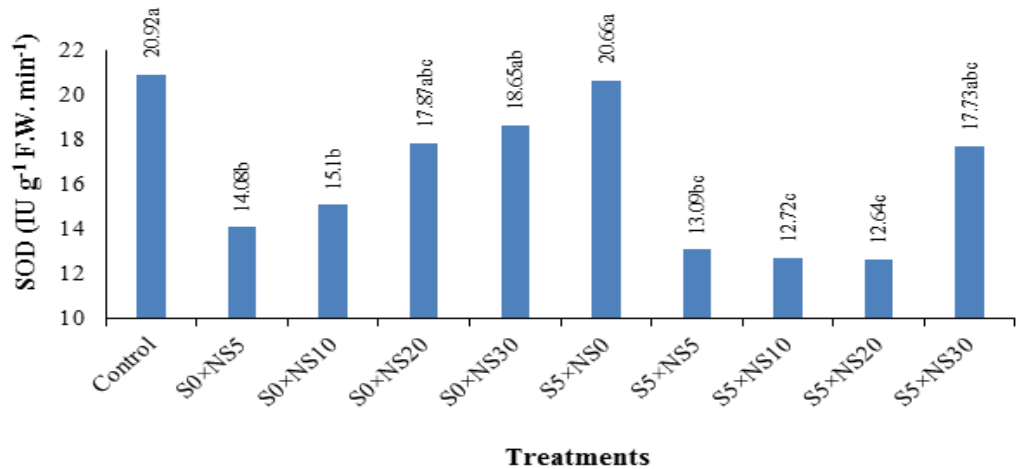

Fig. 7. The interactive effect of "stem-end split (S) × silver nanoparticles (SNP)" on the SOD activity of the cut *Alstroemeria* flowers.

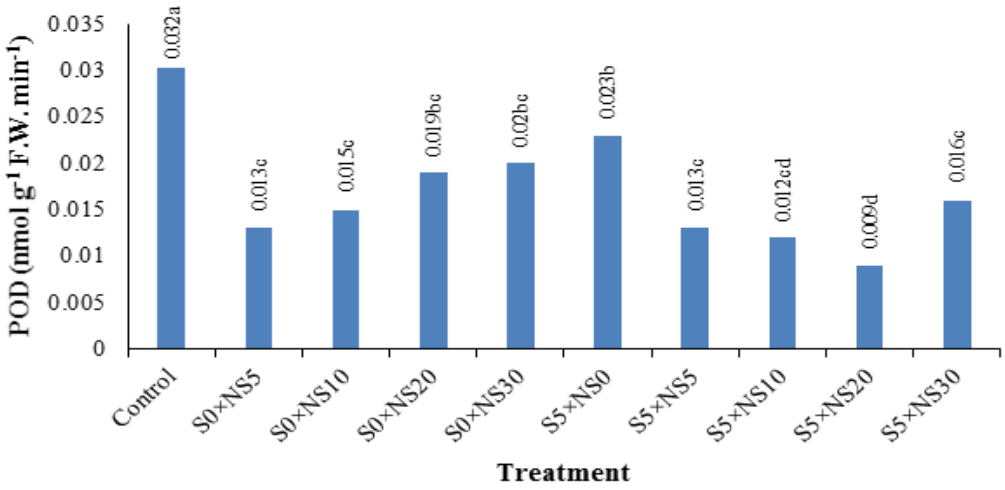

Fig. 8. The interactive effect of "stem-end split (S) × silver nanoparticles (SNP)" on the POD activity of the cut *Alstroemeria* flowers.

DISCUSSION

Vascular blockage and ethylene sensitivity are two factors limiting the postharvest longevity of cut flowers. Various methods have so far been used to cope with these factors, including the application of vase solutions that contain anti-microbial and anti-ethylene compounds. Silver salts are one of the oldest disinfectant and anti-ethylene compounds used in vase solutions. Silver nanoparticles (SNP) contain silver ions in very tiny dimensions, which create a greater contact area. SNP has a higher antimicrobial activity than silver salts. Silver ions prevent vascular blockage and the disruption of water uptake by hindering the growth, reproduction, and activity of bacteria in vase solutions or stem ends of cut flowers through creating complexes with the proteins and organic compounds in their bodies, reacting with their DNAs, and disrupting their cell and respiratory metabolisms (Maneerung *et al*., 2008; Solgi *et al*., 2009; Anvari *et al*., 2022). Similarly, the application of SNP in the present study increased water uptake and subsequently preserved fresh weight by reducing vase solution and stem-end microbial load, thereby increasing dry matter and extending vase life.

Solgi *et al*. (2009) reported that the application of 1 or 2 mg/L SNP in the vase solution of cut gerbera cv. 'Dune' extended its postharvest longevity. Naing *et al*.'s (2017) research revealed that SNP increased water uptake and preserved the freshness of cut carnation flowers by preventing the growth and propagation of bacteria in the vase solution and stem end. The strong antimicrobial effect of SNP and its effect on preserving water uptake and prolonging the longevity of cut flowers have been reported by several researchers (Zhao *et al*., 2018; Ershad Langroudi *et al.,* 2020; Anvari *et al*., 2022).

It has been reported that the application of SNP improves the vase life of ethylene-sensitive cut flowers by preventing ethylene synthesis (Lin *et al*., 2019; Ershad Langroudi *et al*., 2020; Solgi *et al.,* 2011). Silver ions block ethylene receptors, thereby inhibiting the binding of ethylene to its receptors and its activity (Solgi *et al*., 2011). A decrease has been reported in the ethylene synthesis of cut carnation flowers cv. 'Prince' (Lin *et al*., 2019) and 'Omera' (Naing *et al.,* 2017), which corroborates our findings. Halvey and Mayak (2003) reported that the postharvest treatment of cut carnation flowers with silver ion-containing vase solution prolonged postharvest longevity by hindering the growth and propagation of bacteria and inhibiting ethylene synthesis.

Leaf yellowing and shedding are symptoms of chlorophyll degradation and aging in the leaves of *Alstroemeria* (Ferrante *et al.,* 2002). Ethylene is a factor that affects chlorophyll loss and accelerates leaf senescence (Lentini *et al.,* 1988). In the present research, the treatments with a lower rate of ethylene synthesis exhibited a higher amount of chlorophyll, which is in agreement with Lentini (1988). Jowkar *et al*. (2013) stated that the chlorophyll content decreased with flowering aging and that the treatment of cut roses with SNP helped chlorophyll preservation and improved their longevity by improving water relations and retaining cell turgor. The positive effect of SNP on preserving and increasing leaf and petal pigments has been reported by several researchers (Ershad Langroudi *et al*., 2020; Hosseinzadeh *et al*., 2014), supporting our findings.

The increased synthesis of reactive oxygen species (ROS), the accumulation of O_2, H_2O_2, and MDA in plant tissues, and the increase in electrolyte leakage signal the occurrence of oxidative stress and the acceleration of cell aging and death. As senescence starts, the selective permeability of membranes is disrupted and electrolyte leakage increases, so membrane integrity is lost and the cell dies (Jowkar *et al.,* 2013; Xia *et al.,* 2017; Alizadeh Matak *et al*., 2017; Anvari *et al*., 2022). Plants employ enzymatic and non-enzymatic defensive systems to cope with aging and oxidative stress. With the occurrence of stress and the increased level of free oxygen radicals, the antioxidant enzymes like SOD, POD, and CAT become more active to prevent aging and plant death by decomposing these free oxygen radicals (Anvari *et al.,* 2022; Wu *et al.,* 2012). In the present study, SOD and POD activities decreased with the application of SNP versus the control. Also, electrolyte leakage and MDA accumulation were decreased with this treatment, implying the reduction of stress occurrence and the prevention of ROS synthesis. This means that SNP provided ideal conditions for the cut flower until the end of the control's vase life when the activity of the antioxidant enzymes was measured. Various studies have reported the effect of SNP on preserving membrane health, reducing MDA, and increasing the activity of antioxidant enzymes (Zhao *et al.*, 2018; Hassan *et al.,* 2014; Cheng *et al*., 2012; Wu *et al*., 2012).

The stem-end split also influenced vase life and other recorded traits positively. Since the retention of water uptake is the most important factor in preserving the vase life of cut flowers, it seems that the stem-end split expands the contact area of the stem with the vase solution and increases the stem's uptake area. The split stem can, on the other hand, be a good place for the growth of microorganisms and cause vascular blockage, but disinfectants limit microbe growth and contribute to preserving freshness and cell turgor, which are requirements for the natural activity of the cells and their survival, by retaining water uptake (Dashtbany and Hashemabadi, 2015; Ahmad *et al.,* 2011; Sadeghi Hafshejani and Hashemabadi, 2016). Sadeghi Hafshejani and Hashemabadi (2016) reported that the application of a disinfectant along with a 5 cm split of the stem end of *Alstroemeria* increased water uptake, dry matter, pigments, and vase life. Razi (2017) reported a decrease in vase solution bacteria, an increase in chlorophyll a, b, and total, a decrease in ethylene synthesis, and an increase in vase life of cut *Alstroemeria* with the application of "200 mg/L Lawson essential oil × 5-cm stem-end split". Similar results were reported by Dashtbany and Hashemabadi (2015) regarding the positive effect of "stem-end split × disinfectant" on the vase life, which is consistent with our results.

CONCLUSIONS

Making a 5-cm split in the stems of cut *Alstroemeria* along with the application of SNP significantly contributed to the improvement of water uptake, the control of ethylene

production, the preservation of membrane structure (the reduction of electrolyte leakage and MDA), and the extension of vase life. The most effective treatment for the recorded traits was "5-cm stem-end split × 20 mg L^{-1} SNP". The application of 30 mg L^{-1} SNP at both stem-end split levels negatively influenced all recorded traits compared to the SNP rates of 5, 10, and 20 mg L^{-1}, reflecting the toxic effect of SNP at high rates on plant tissues. So, the application of "5-cm stem-end split × 20 mg L^{-1} SNP" is recommended for preserving and increasing the longevity of cut *Alstroemeria* cv. 'Konst Coco' flowers.

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