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EFFECT OF BLUE LIGHT AND NANOSILVER ON VASE LIFE, ANTIOXIDANT ENZYMES AND SOME OTHER PHYSIOLOGIC PARAMETERS OF *Alstroemeria* 'Napoli' CUT FLOWERS

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ABSTRACT

The effects of postharvest blue light exposure have never been studied on cut flowers, so the present study aimed to explore the effects of blue light exposure duration (6, 12, 18, and 24 h) and silver nanoparticle (SNP) application (5, 10, 15, and 20 mg l^{-1}) on the quantitative and qualitative traits of cut *Alstroemeria* 'Napoli' flowers. The control flower received distilled water without blue light exposure. The longest vase life (22.66 days) was related to 10 mg l^{-1} SNP, not differing from 12 h of blue light exposure (22.00 days) and 20 mg l^{-1} SNP (21.66 days), significantly. The highest water uptake and total chlorophyll and the lowest ethylene were obtained from the flowers treated with 10 mg l^{-1} SNP or exposed to 12 h of blue light. These two treatments outperformed the control in reducing MDA accumulation too. APX activity was significantly higher in the flowers treated with 12 h of blue light exposure, 18 h of blue light exposure, or 15 mg l^{-1} SNP. Except for the blue light exposure for 6 h, all treatments reduced stem-end bacteria versus the control. The lowest bacterial population (57.3 Log_{10} CFU ml^{-1}) belonged to the flowers treated with 15 mg l^{-1} SNP. Blue light outperformed SNP in stopping the growth of Gram-positive bacteria and yeast. Based on the results, blue light is introduced as a physical factor to improve the quantitative and qualitative traits of cut *Alstroemeria* 'Napoli' flowers.

Key words: ascorbate peroxidase, gram-negative bacteria, gram-positive bacteria, yeast, vase solution

INTRODUCTION

The vase life of cut *Alstroemeria* is influenced by water stress and ethylene production. Water stress and ethylene production activate the microorganisms' proliferation in the vase solution and stem, induce early senescence and wilting, in turn, impairs the marketability of cut *Alstroemeria* flowers [Chanasut et al. 2003, Edrisi 2009]. Silver ion possesses antimicrobial and anti-ethylene activities. Silver ions hinder the growth and propagation of bacteria through disrupting cell and respiratory metabolisms of the bacteria and induce their programmed death. Nanosilver is a compound of silver ions in tiny dimensions with high contact area. Silver ions in nano dimensions exhibit more antimicrobial activity than silver salts [Maneerung et al. 2008, Solgi et al. 2009, 2011]. The positive effect of nanosilvers has been reported on extending the vase life of various cut flowers. For instance, it was reported that silver in the preservative solution of cut

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carnation flowers acted as a strong antibacterial and anti-ethylene compound and increased the postharvest longevity of this cut flower significantly versus the control [Halvey and Mayak 2003]. Morones et al. [2005] argue that silver nanoparticles (SNP) increase water uptake and postharvest longevity of cut flowers by inhibiting the growth and propagation of bacteria in the vase solution and stem end. Solgi et al. [2009] reported that the vase life of cut gerbera flowers cv. Dune was doubled by the application of 1 or 2 mg l^{-1} SNP versus the control.

Blue light (ranging 400–500 nm) is a vital environmental factor in plants, which is involved in a wide range of growth, development and flowering processes, stomatal opening and closing, resistance to pathogens, impact on photosynthesis, pigment biosynthesis, flavonoid biosynthesis, ethylene biosynthesis and so on [Lin 2000, Christie and Briggs 2001, Shi et al. 2014]. Shi et al. [2014] recommend blue light exposure as a useful technique to increase the nutritional and commercial value of fruits. There are many studies reported about the role of blue light in the synthesis and improvement of phenol compounds, vitamin C, and carotenoids in carrots [Samuoliene et al. 2013, Bantis et al. 2016], as well as the increments in anthocyanin and genes expression related to anthocyanin biosynthesis and maturity in strawberries as affected by blue light. The blue light delayed ethylene peak and increased total dissolved solids in peaches [Gong et al. 2015].

In Alferez et al. [2012] study, blue light exposure reduced decay, increased pigment biosynthesis, and mitigate postharvest fungal infections and diseases in citrus. Liao et al. [2013] stated that the exposure of oranges to blue light reduced fungal growth and decay caused by fungal infections. Jerzy et al. [2011] studied the effect of light color on bud opening and postharvest life of chrysanthemum. They used supplementary light at the postharvest stage provided by florescent lamps with blue light in the range of 400–580 nm. The results revealed that the flowers treated with blue light had more opened buds than the other treatments. Flower growth and development were higher in the flowers exposed to blue light than those exposed to white or green light. The longevity of the chrysanthemum flowers was in the order of blue light > white light > green light. The shortest longevity was related to the flowers exposed to red light.

So far, no research has addressed the impact of postharvest blue light exposure on cut flowers. So, the present study aimed to shed light on the effects of different durations of blue light (470 nm) exposure and pulsed treatment of silver nanoparticles on the postharvest longevity, ethylene synthesis, bacteria population and species at the stem end, and antioxidant enzyme activity of cut alstroemeria 'Napoli' flowers.

MATERIALS AND METHODS

The effects of blue light exposure and pulsed treatment of silver nanoparticles (SNP) were studied on the postharvest longevity of cut *Alstroemeria* 'Napoli' flowers in an experiment based on a completely randomized design with nine treatments and three replications. The flowers were harvested at the commercial stage (with two bloomed florets from each flower bench) and were immediately transferred to the laboratory. The flowers were re-cut to a height of 40 cm under tap water in the laboratory and were kept in containers containing distilled water to be exposed to the treatments. The treatments included the duration of exposure to blue light (470 nm) at the rate of 6, 12, 18, or 24 h and the pulse treatment of SNP at rates of 5, 10, 15, or 20 mg l^{-1}, in addition, to the control flowers (without distilled water). After 24 h, the flowers were transferred to a solution containing 3% sucrose and remained in this solution until the end of the experiment. The treated flowers were kept in the laboratory at 20 ±2°C and 60–75% relative humidity until the end of the experiment. The light intensity applied to the SNP-treated and control flowers was 15 μmol m^{-1} s^{-1} for 12 h a day.

Vase life. It was recorded by counting days from the initiation of the cut flowers' treatment with blue light and SNP until the shedding of 50% of the petals [Mutui et al. 2006].

Water uptake. At first, 500 ml of preservative solution were poured in the vase and the flowers were placed inside it. A part of the water was absorbed by flowers and the part was evaporated. At the end of the vase life of the last flower, the remaining solution volume was calculated and the volume of evaporation was added and sum of them was deducted from 500 ml. The obtained number was the water that was absorbed by flowers. The absorbed water was divided into flow-

er weight and the water absorption rate was obtained in ml g^{-1} FW. The amount of water taken up by the cut flowers was calculated by the following equation:

$$\text{Solution uptake (mg g – 1 FW)} = \frac{V_{t0} - (E_t + V_{t1})}{\text{FW}}$$

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 FW is the flowers' fresh weight on day 1.

Stem-end bacteria count and identification. Twenty-four h after the treatments, 2 cm was cut from the stem end. It was then washed with 70% ethanol and was crushed with 0.9% normal saline serum in a sterile environment. Then, 0.1 ml of the solution extracted from the crushed stem was cultured on plate count agar. It was kept at 30°C for 48 h and then, the bacterial colonies (the unit: Log_{10} CFU ml^{-1}) were counted by an optical microscope [Liu et al. 2009]. After the bacteria were counted, the morphology of the colonies was studied and the colonies with different morphologies were randomly sampled for further examination. Some studied morphological and biochemical traits included staining properties and morphology in Gram staining, the growth and morphology of colonies on McConkey agar medium, mobility, oxidase and catalase production, gelatin hydrolysis, starch hydrolysis, indole synthesis, urease production, methyl red reaction, acetoin (VP) production, the use of citrate, nitrate reduction, and H_2S production among the selected colonies.

Total chlorophyll. The leaves of alstroemeria were sampled on day 17 (first symptoms of wilting in vase life room) for which 0.5 g of the leaves was extracted with 80% acetone in a mortar. The absorbance of the resulting samples was read at 642 and 660 nm with a spectrophotometer (Shimadzu UV-120-02, Japan) and then, the following equation was used to calculate chlorophyll content in mg g^{-1} FW [Mazumdar and Majumder 2003]:

$$\text{Total chlorophyll} = 7.12\ (A_{660}) + 16.8\ (A_{642})$$

Petal carotenoids. The content of petal carotenoids was measured by observing the first symptoms of wilting of flowers in the vase life room. Sampling was carried out from open flowers on the inflorescence. To measure petal carotenoids, extraction was performed with 80% acetone. The absorbance of the extract was read with a spectrophotometer (Shimadzu UV-120-02, Japan) at 440, 645, and 663 nm and then, the following equation was used to calculate carotenoid content in μg g^{-1} FW [Mazumdar and Majumder 2003]:

$$\text{Petal carotenoids} =$$
$$= (4.69 \times A_{440}) - (0.286 \times 20.2 \times A_{645}) + (8.02 \times A_{663})$$

Petal anthocyanin. The content of petal anthocyanin (in mg per 100 g FW) was measured by observing the first symptoms of wilting of flowers in the vase life room. Sampling was carried out from open flowers on the inflorescence. Acidic methanol (pure methanol + 1% hydrochloric acid) was used to extract the anthocyanin from petals. The absorbance of the infiltrated extract was read at 535 nm with a spectrophotometer (Shimadzu UV-120-02, Japan), and anthocyanin content was calculated by the following equation [Jadid Solimandarabi et al. 2017]:

$$\text{Anthocyanin (mg/100 g FW)} = \frac{e \times b \times c}{d \times a} \times 100$$

in which; *e* is the sample weight, *b* is the volume of the sample taken for the measurement, *c* is the total prepared solution, *d* is the volume of the taken sample, and *a* is the reading.

Ethylene production. To measure the ethylene produced by the cut alstroemeria flowers, 24 h after the treatments, one flower was selected from each plot and was vacuumed in specific jars. After 24 h, the ethylene gas produced in the jars was sampled, and its ethylene content was measured with a gas chromatography instrument (Shimadzu GC-2014, Japan) and reported in nl l^{-1} g^{-1} FW [Alizadeh Matak et al. 2017].

Malondialdehyde (MDA). The rate of MDA was determined by observing the first symptoms of wilting of flowers in the vase life room. Sampling was carried out from open flowers on the inflorescence. To determine MDA content, 0.5 g of the petal tissue was extracted by liquid nitrogen and it was added with 1 ml of potassium phosphate buffer and 0.5 mol of EDTA. The resulting solution was centrifuged at 14000 rpm at 4°C

for 20 min. The supernatant was sampled and mixed with 1000 µl of trichloroacetic acid (TCA) and thiobarbituric acid reactive substance (TBAS). The samples were kept at 95°C for 30 min and they were, then, transferred into an ice-containing container. After they cooled, the samples were centrifuged as long as the red MDA content of thiobarbituric acid emerged. The absorbance of the samples was read at 532 and 600 nm and the following equation was used to determine the MDA content of the petal tissues in nmol g^{-1} FW [Heath and Parker 1968]:

$$\text{MDA (nmol g – 1 FW)} = \frac{[6.45\ (A532 - A600) - 0.56\ A450]}{\text{fresh weight}}$$

Antioxidant enzymes. To measure the activity of antioxidant enzymes (after observing the first symptoms of wilting of flowers), an enzymatic extract was first prepared for which the petals of alstroemeria were extracted with 50 mmol potassium phosphate buffer. Then, it was centrifuged at 10500 rpm at 4°C for 25 min. Using a sampler, the transparent supernatant of the sample was taken and used as the enzymatic extract.

To determine peroxidase (POD) activity, 100 µl of the enzymatic extract was mixed with 450 µl of guaiacol and 450 µl of H_2O_2. The absorbance was read at 470 nm with a spectrophotometer (JASCO V530, Japan) and reported as the POD activity (in nmol g^{-1} FW) [In et al. 2007].

To estimate superoxide dismutase (SOD) activity, 0.1 ml of the enzymatic extract was mixed with 25 ml of nitro blue tetrazolium chloride (NBT), 0.1 mmol of EDTA, 13 mmol of methionine, 50 mmol of potassium phosphate buffer, and 50 mmol of sodium carbonate and was placed in a shaker at 22°C under fluorescence to be shaken gently for 30 min. At the next step, the samples were kept in a dark room for 30 min. Then, the absorbance was read at 560 nm with a spectrophotometer (JASCO V530, Japan) and reported in IU g^{-1} FW min^{-1} [Giannopolitis and Ries 1997].

To determine ascorbate peroxidase (APX) activity, 150 µl of the enzymatic extract was well mixed with 50 mmol of potassium phosphate buffer, 0.5 mmol of ascorbate, and 0.1 mmol of H_2O_2 with a shaker. The absorbance was read at 290 nm with a spectrophotometer (JASCO V530, Japan) and reported in Units mg^{-1} protein min^{-1} [Nakano and Asada 1981].

Statistical analysis. The statistical analysis was performed in the SPSS statistical software package (ver. 19) and the means were compared by the LSD test.

RESULTS

Vase life. The effects of blue light exposure and different SNP levels were significant ($P < 0.01$) on vase life (Tab. 1). Based on the mean comparison, almost both treatments prolonged vase life versus the control (19 days). The longest vase life was related to the application of 10 mg l^{-1} SNP (22.66 days), but it did not differ from the plants treated with blue light for 18 h (22.00 days) and those treated with 20 mg l^{-1} SNP (21.66 days) significantly (Tab. 2).

Water uptake. The effects of the experimental treatments were significant ($P < 0.01$) on water uptake (Tab. 1). All treatments increased this trait versus the control (1.40 mg g^{-1} FW). The highest was observed in the plants treated with 10 mg l^{-1} SNP (2.07 mg g^{-1} FW), just insignificantly differing from those treated with blue light for 12 h (1.90 mg g^{-1} FW), blue light for 18 h (1.87 mg g^{-1} FW), or 15 mg l^{-1} SNP (1.87 mg g^{-1} FW) (Tab. 2).

Stem-end bacteria count and identification. The results of the analysis of variance (ANOVA) revealed that the stem-end bacteria population was significantly ($P < 0.01$) influenced by the duration of blue light exposure and different levels of SNP (Tab. 1). Stem-end bacteria were most crowded (243 Log_{10} CFU ml^{-1}) in the flowers exposed to blue light for 8 h, not significantly differing from the control (223 Log_{10} CFU ml^{-1}). As can be observed in Table 2, the stem-end bacteria population was significantly decreased by the application of SNP and with the increase in the duration of blue light exposure. The lowest stem-end bacteria population (57.3 Log_{10} CFU ml^{-1}) was obtained from the application of 15 mg l^{-1} SNP. Among the different levels of blue light exposure, the lowest stem-end bacteria population was related to the exposure duration of 24 h (111 Log_{10} CFU ml^{-1}) and 12 h (116 Log_{10} CFU ml^{-1}), not differing with one another significantly (Tab. 2). Table 3 presents the genera of the bacteria grown at the stem end. It is observed that genera of Gram-positive and Gram-negative bacteria and yeast

were identified in the control treatment. Among the different levels of SNP, the two rates of 15 and 20 mg l^{-1} completely inhibited the growth of Gram-negative bacteria, but Gram-positive bacteria and yeast were detected in this treatment. On the stems of the flowers exposed to blue light, only Gram-negative bacteria were detected and the blue light inhibited the growth of Gram-positive bacteria and yeasts.

Total chlorophyll. The effects of blue light exposure duration and pulse treatment of cut flowers with different levels of SNP were significant ($P < 0.01$) on total chlorophyll content (Tab. 1). All four levels of SNP were related to higher total chlorophyll than the control (2.72 mg g^{-1} FW), but this trait was decreased as the SNP level was increased from the rate of 5 mg l^{-1} to the rate of 20 mg l^{-1}. However, chlorophyll content in 5 and 20 mg l^{-1} SNP was higher than that of control, but differences were not significant. The application of blue light for 6, 12, and 18 h successfully increased total chlorophyll versus the control, but its application for 24 h (2.65 mg g^{-1} FW) did not differ from the control significantly. Overall, the best treatments for total chlorophyll enhancement were found to be 12 h of light blue exposure (5.05 mg g^{-1} FW), 10 mg l^{-1} SNP (4.56 mg g^{-1} FW), 18 h of light blue exposure (4.41 mg g^{-1} FW), 15 mg l^{-1} SNP (4.07 mg g^{-1} FW), and 6 h of blue light exposure (4.03 mg g^{-1} FW), not differing from one another significantly (Tab. 2).

Petal carotenoids. Based on ANOVA, the experimental treatments changed petal carotenoids significantly at the $P < 0.01$ level (Tab. 1). All experimental treatments increased this trait versus the control (0.44 µg g^{-1} FW), however, petal carotenoid content in flowers placed into 5 mg l^{-1} SNP and flowers treated with blue light (6 h) was higher than that of control, but differences were not significant. The highest petal carotenoids (0.76 µg g^{-1} FW) was obtained from the flowers exposed to blue light for 18 h, but it did not differ from 12 h of light blue exposure (0.67 µg g^{-1} FW) and 10 mg l^{-1} SNP (0.69 µg g^{-1} FW), significantly (Tab. 2).

Petal anthocyanins. The effects of blue light exposure and SNP were significant ($P < 0.01$) on petal anthocyanin (Tab. 1). Although, all experimental treatments increased petal anthocyanin versus the control (4.61 mg 100 g^{-1} FW), the best treatments were 10 mg l^{-1} SNP (11.50 mg 100 g^{-1} FW) and blue light exposure for 24 h (10.68 mg 100 g^{-1} FW), which did not differ to one another significantly (Tab. 2).

Ethylene production. Based on the results of ANOVA, ethylene production was significantly ($P < 0.01$) influenced by the experimental treatments (Tab. 1). The treatment of the alstroemeria cut flowers with different levels of SNP and blue light exposure reduced ethylene synthesis when compared with the control (10.85 nl l^{-1} g^{-1} FW). There was, however, no significant difference between the control and the flowers exposed to blue light for six h (10.52 nl l^{-1} g^{-1} FW). The lowest amount of ethylene production (1.12 nl l^{-1} g^{-1} FW) was related to the flowers exposed to blue light for 12 h, which did not differ from that of the treatments of 10 and 15 mg l^{-1} SNP, significantly (Tab. 2).

Malondialdehyde (MDA). The effect of the experimental treatments was significant ($P < 0.01$) on MDA accumulation (Tab. 1). According to the comparison of the mean, the highest MDA (3.68 nmol g^{-1} FW) was

Table 1. Analysis of variance for the effect of different treatments (blue light durations and silver nanoparticle levels) on the vase life, water uptake, bacterial population at stem end, total chlorophyll, petal carotenoids and anthocyanin, ethylene production, malondialdehyde (MDA), superoxide dismutase (SOD), peroxidase (POD), and ascorbate peroxidase (APX)

Source of variance	df	Vase life	Water uptake	Bacterial population at stem end	Total chlorophyll	Petals carotenoids	Petals anthocyanin	Ethylene production	MDA	SOD	POD	APX
Treatment	8	4.64**	0.0998**	13351**	1.97**	0.0319**	14.1**	46.2**	1.26**	18.1**	0.00202**	59.4**
Error	16	0.377	0.0142	191.66	0.471	0.003	0.563	2.083	0.277	3.708	0.0001	2.333
C.V. (%)	–	2.94	6.60	10.10	17.85	9.69	9.33	23.36	20.21	6.41	11.65	20.80

** – significant at $P < 0.01$; MDA – malondialdehyde; SOD – superoxide dismutase; POD – peroxidase; APX – ascorbate peroxidase

obtained from the flowers exposed to 6 h of blue light although it did not differ from the control (3.13 nmol g^{-1} FW) and the treatments of 5 and 20 mg l^{-1} SNP significantly. MDA content in flowers placed into 10 and 15 mg l^{-1} SNP was higher than the control, but differences were not significant. The lowest MDA accumulation was related to the flowers treated with blue light for 12 h in which it was 1.53 nmol g^{-1} FW (Tab. 2).

Superoxide dismutase (SOD) activity. ANOVA showed that the effects of blue light exposure and SNP on SOD activity were significant ($P < 0.01$) (Tab. 1). According to the comparison of the means, the lowest

Table 2. Means comparison for the effect of different treatments (blue light durations and silver nanoparticle levels) on the vase life, water uptake, bacterial population at stem end, total chlorophyll, petal carotenoids and anthocyanin, ethylene production, malondialdehyde (MDA), superoxide dismutase (SOD), peroxidase (POD), and ascorbate peroxidase (APX)

Treatments	Vase life (day)	Water uptake (mg g^{-1} FW)	Bacterial population at stem end (Log_{10} CFU ml^{-1})	Total chlorophyll (mg g^{-1} FW)	Petals carotenoids (µg g^{-1} FW)	Petals anthocyanin (mg 100 g^{-1} FW)	Ethylene production (nl L^{-1} h^{-1} g^{-1} FW)	MDA (nmol g^{-1} FW)	SOD (IU g^{-1} FW min^{-1})	POD (nmol g^{-1} FW)	APX (units mg $^{-1}$ protein min^{-1})
Control	19.00e	1.40d	223.0a	2.72c	0.44e	4.61d	10.85a	3.13ab	34.44a	0.101b	1.05f
Nanosilver pulse treatment (mg l^{-1})											
5	20.66cd	1.83bc	194.0b	3.70 bc	0.51de	8.56b	7.75c	2.95a-c	28.49bc	0.079cd	6.40cd
10	22.66a	2.07a	93.6de	4.56ab	0.69ab	11.50a	1.30d	2.05cd	28.78b	0.048g	8.75bc
15	21.50bc	1.87a-c	57.3f	4.07 ab	0.62bc	8.72b	1.42d	2.13cd	30.47b	0.089bc	10.05b
20	21.66a-c	1.69c	74.0ef	3.40 bc	0.56cd	6.62c	8.24bc	2.96a-c	30.47b	0.132a	4.45de
Duration of blue light exposure (h)											
6	19.50e	1.77bc	243a	4.03 ab	0.51de	6.57c	10.52ab	3.68a	30.77b	0.073de	2.70ef
12	22.0ab	1.90 ab	116cd	5.05a	0.67ab	6.65c	1.12d	1.53d	25.31c	0.061e-g	13.10a
18	21.50bc	1.87a-c	120c	4.41 ab	0.76a	8.49b	6.28c	2.51bc	31.36ab	0.066d-f	13.90a
24	19.83de	1.80bc	111cd	2.65c	0.65bc	10.68a	8.13bc	2.53bc	30.37b	0.056fg	5.70d

*In each column, means with similar letter(s) are not significantly different ($P < 0.05$) using the LSD test

Table 3. The general of the bacteria detected at the stem end

Treatments	Gram-negative bacteria	Gram-positive bacteria	Fungus
Control	*Pseudomonase, Escherichia coli*	*Staphylococcus*	Yeast
Nanosilver pulse treatment (mg l^{-1})			
5	*Pseudomonase, Escherichia coli*	*Bacillus, Staphylococcus*	–
10	*Escherichia coli*	*Bacillus*	–
15	–	*Bacillus*	Yeast
20	–	*Staphylococcus*	Yeast
Duration of blue light exposure (h)			
6	*Escherichia coli, Citrobacter*	–	–
12	*Escherichia coli, Citrobacter*	–	–
18	*Escherichia coli*	–	–
24	*Escherichia coli, Entroobacter*	–	–

SOD activity was observed in the flowers exposed to blue light for 12 h (25.31 IU g^{-1} FW min^{-1}) followed by those treated with 5 (28.49 IU g^{-1} FW min^{-1}) and 10 mg l^{-1} SNP (28.78 IU g^{-1} FW min^{-1}). The highest SOD activity was related to the 20 mg l^{-1} SNP (34.44 IU g^{-1} FW min^{-1}) (Tab. 2).

Peroxidase (POD) activity. Data in Tables 1 and 2 indicate that POD activity was significantly ($P < 0.01$) increased in the flowers treated with 20 mg l^{-1} SNP (0.132 nmol g^{-1} FW). The lowest POD activity (0.048 nmol g^{-1} FW) was recorded by the 10 mg l^{-1} SNP. Among the flowers exposed to blue light, the lowest and highest POD activities were observed in the flowers exposed for 24 h (0.056 nmol g^{-1} FW) and those exposed for 6 h (0.073 nmol g^{-1} FW), respectively (Tab. 2).

Ascorbate peroxidase (APX) activity. The effects of blue light exposure and SNP were significant ($P < 0.01$) on APX activity (Tab. 1). Among the treatments, the control had the lowest APX activity (1.05 units mg^{-1} protein min^{-1}). Among different levels of blue light exposure, 12 and 18 h were related to the highest APX activity and 6 h was related to the lowest activity (2.70 units mg^{-1} protein min^{-1}). As for the different levels of SNP, the highest and lowest APX activities were recorded by 10 and 20 mg l^{-1} levels, respectively (Tab. 2).

DISCUSSION

Microorganisms are the most common cause of vascular occlusion and the loss of postharvest vase life of cut flowers. In addition to vascular occlusion, microorganisms have been reported to play a role in the synthesis of toxins, proteolytic enzymes, and ethylene and the acceleration of the senescence process [van Doorn 2012, Fazlalizadeh et al. 2013]. SNP is an antibacterial and anti-ethylene compound whose application in the preservative solution of cut flowers hinders the destructive impacts of ethylene and microorganisms [Lin et al. 2019a, b]. Researchers suggest that the silver content of SNP disrupts cell respiration, electron transport, and the mobilization of materials across the cell membrane of bacteria and they inhibit the vascular occlusion by reducing the activity and/or causing the death of bacteria, thereby they preserve water uptake and prolong the longevity of cut flowers [Paull and Lyons 2008, Ershad Langroudi et al. 2019, García-Ramírez et al. 2019]. In the present study too, SNP reduced ethylene production and stem-end bacteria population versus the control, resulting in a higher rate of water uptake and longer vase life of the cut *Alstroemeria* 'Napoli' flowers. In Lin et al. [2019b] study, the application of SNP + 3% sucrose in the preservative solution of cut carnation flowers cv. Prince reduced ethylene production, increased solution uptake, and extended vase life. SNP increases vase solution uptake by reducing microorganism growth and protecting the hydraulic conductivity of the stems, thereby preserving flower freshness for a longer time [van Doorn 2012]. SNP was effective in improving the vase life of ethylene-sensitive cut flowers through inhibiting the ethylene activity [Lin et al. 2019b].

Naing et al. [2017] reported that the application of 25 mg l^{-1} SNP reduced ethylene production and prolonged the longevity of cut carnation flowers cv. Omea. Also, the treatment of the cut carnation flowers with 25 or 50 mg l^{-1} SNP stopped the production of bacteria versus the control. A strain of *E. coli* was the most abundant bacteria in Naing et al. [2017] study. The positive effect of SNP has been reported on preserving the freshness and extending the postharvest longevity of the cut flowers of carnation 'Master' [Liu et al. 2014], gerbera [Motughayer et al. 2019], and gladiolus 'Eerde' [Li et al. 2017], which is in agreement with our findings.

In the present study, in addition to the impact of SNP on reducing bacterial colonies, its 5 and 10 mg l^{-1} rates stopped yeast growth and its 15 and 20 mg l^{-1} rates stopped the growth of Gram-negative bacteria. van Doorn and de Witte [1994] reported that *Pseudomonas* and *Enterobacteria* were the dominant bacterial species at the stem ends of cut roses. The results of Jowkar [2006] revealed that the dominant microorganisms at the stems of *Narcissus tazetta* L. included *Actinomycetes*, *Staphylococcus*, and *Bacillus*.

Senescence is essentially accompanied by chlorophyll loss and degradation. Leaf yellowing in the cut alstroemeria flowers is also a sign of the initiation of senescence and chlorophyll degradation [Ferrante et al. 2002]. The presence of chlorophyll in plant tissues signals that the cells are active and sugar compounds are synthesized by them. Sugar compounds accelerate senescence by adjusting cell respiration and osmotic

pressure [Tanazad et al. 2016]. Researchers suggest that ethylene sensitivity is a reason for the loss of chlorophyll in leaves. They argue that ethylene causes the transport and reduction of chlorophyll and increases the rate of senescence in plant tissues [Lentini et al. 1988]. In the present work, the treatment of the cut alstroemeria flowers with SNP increased chlorophyll content versus the control. Data in Table 2 show that among different levels of SNP, the flowers that produced less ethylene possessed more ethylene. So, it can be inferred that SNP contributes to preserving chlorophyll pigments in the alstroemeria leaves by inhibiting ethylene synthesis. Ershad Langroudi et al. [2019] reported that the 24-h pulsed application of SNP hindered the degradation of carotenoids in cut alstroemeria flowers. In Hosseinzadeh et al. [2014] study, the treatment of cut roses with SNP helped the flowers to keep or even increase their anthocyanin. The effect of disinfectants on increasing the pigments of leaves and petals of cut flowers has been reported in various studies [Basiri et al. 2011, Hashemabadi 2014], which corroborates our findings.

Senescence is the result of reactive oxygen species (ROS) production and oxidative processes in plant tissues. There are reports that when senescence is accelerated in plant tissues, reactive oxygen radicals are produced continuously and at a high rate, and more O_2, H_2O_2, and MDA are accumulated in plant tissues. With the initiation of senescence, membrane permeability increases, its integrity is gradually lost, and cell death occurs [Bartoli et al. 1995, Ohe et al. 2005, Kumar et al. 2010, Xia et al. 2017]. Antioxidant enzymes, e.g. SOD, POD, CAT, and APX, suppress the activity of reactive radicals during senescence [Xu et al. 2014b]. In fact, antioxidants retard senescence and flower wilting by suppressing ROS and alleviating the damages of the stresses [Palma et al. 2002, Tanazad et al. 2016]. In the present study, SOD activity was decreased versus the control by all four levels of SNP, and POD activity was reduced by the SNP rates of 5, 10, and 15 mg l^{-1}, but APX activity was increased at all four levels of SNP. Since SNP application reduced MDA accumulation versus the control, it can be concluded that SNP application in the vase solution hinders the emergence of stressful conditions (water stress), ROS activity, lipid peroxidation, and MDA accumulation and reduce SOD and POD activity versus the control. Mishra and Jha [2011] reported that APX played a key role in ROS scavenging and cell protection against stresses imposed on higher plants and algae. It has been reported that APX has a high capacity to stick to H_2O_2, thereby protecting the plants against toxicity. But, the other antioxidants can just increase the rate of this reaction, but they cannot stick to H_2O_2, so they are less effective than APX in H_2O_2 suppression [Montazerinezhad et al. 2013]. Therefore, the higher activity of APX in the present research versus POD and SOD can be related to the higher sensitivity of this enzyme to stressful conditions.

Zhao et al. [2018] found that the application of SNP reduced MDA and increased SOD, CAT, and APX activity in cut *Paeonia lactiflora* flowers. In Hassan et al. [2014] study, SNP application resulted in a decline in MDA and H_2O_2 accumulation in roses. An increase in antioxidant activities and a decrease in the damages of ROS activities have also been reported in gerbera and carnation due to SNP application [Cheng et al. 2012, Wu et al. 2012], which is consistent with our findings. Kazemipour et al. [2016] stated that the application of longevity extending compounds, e.g. SNP, in the vase solution of cut chrysanthemum flowers increased SOD activity, alleviated oxidative stress, reduced MDA, and protected membrane health. The researchers noted that SNP and sodium silicate mitigated water and oxidative stresses and retarded senescence in the cut chrysanthemums by increasing antioxidant activities and reducing MDA accumulation. This is in agreement with our findings.

Postharvest blue light exposure of the cut alstroemeria flowers was addressed here for the first time. Previous studies on the effect of postharvest blue light exposure have dealt with different fruits whose results have revealed the positive effect of this treatment on the control of fungal infections and decay of the fruits over the storage period [Alferez et al. 2012, Liao et al. 2013]. In the present work, blue light exposure reduced the stem-end microbial load significantly. The growth of Gram-positive bacteria and fungi at the stem end was stopped in the flowers exposed to blue light. But, *E. coli* was observed in the stem ends even in the treated flowers, reflecting the resistance of this bacterial species to blue light. Liao et al. [2013] reported that blue light exposure reduced postharvest decay of citrus. They stated that the decay control in blue

light-exposed citrus was related to the impact of blue light on the reduction of fungal growth, induction of defensive responses in the host, and the reduction of the activity of cell wall digesting enzymes. It was reported that fungal growth and activity were decreased in tangerines exposed to blue light during the postharvest period [Alferez et al. 2012], which supports our findings. Given the relationship between water uptake and stem-end microbial population, it can be said that blue light protects the balance in water uptake by reducing stem-end microbial load, thereby extending the longevity of cut alstromeria flowers. Jerzy et al. [2011] found that the cultivation of chrysanthemum flowers under blue light increased their vase life. Sedaghathoor [2015] studied the effects of wall color (blue, red, brown, and white) and SNP on the vase life of cut carnation flowers and obtained the longest vase life from the combination of white light × 5 mg l^{-1} SNP (18.32 days) followed by blue × 5 mg l^{-1} SNP (17.1 days).

Blue light exposure is an effective technique to improve the color and commercial value of horticultural products [Yuan et al. 2017]. Light, especially blue light, is involved in the biosynthesis of anthocyanin [Xu et al. 2014a, b]. Shi et al. [2014] reported that blue light exposure increased the expression of the genes that were responsible for the biosynthesis and regulation of anthocyanin in Chinese bayberry fruits. Similarly, we observed that the anthocyanin content was higher in the petals of the flowers exposed to blue light than the control. Xu et al. [2014a, b] stated that blue light was effective in stimulating the accumulation of anthocyanin in the harvested strawberries. In Yuan et al. [2017] study, blue light exposure improved skin color and carotenoid accumulation in ethephon-treated mandarin fruits. In the present study too, blue light exposure improved petal carotenoids and anthocyanin versus the control. The exposure of the cut flowers to blue light for 18 h increased chlorophyll content vis-à-vis the control. Ethylene synthesis was decreased in blue light-treated flowers as compared with the control. Ma et al. [2014] reported that blue light exposure did not influence ethylene synthesis in broccoli significantly. They found that blue light-treated broccolis had lower ethylene than the control until day 3, but from day 4 after harvest on, ethylene synthesis was increased in the flowers exposed to blue light although the differences were not statistically significant. According to Xu et al. [2014b], strawberries exposed to blue light exhibited a higher rate of ethylene synthesis. Similar results were reported by Gong et al. [2015].

Blue light exposure for 12, 18, and 24 h reduced MDA accumulation in the cut alstroemeria flowers versus the control. At all four levels of blue light exposure, SOD and POD were less active than the control, whereas APX activity in these treatments was significantly higher than that in the control. This means that in plants exposed to blue light, stress is controlled by the increased activity of APX, which is more sensitive to stress-inducing factors than the other antioxidant enzymes. According to Xu et al. [2014b], blue light exposure during storage increased the activity of SOD, APX, and CAT and decreased H_2O_2 and MDA accumulation. The results as to the increase in APX activity and the decrease in MDA accumulation are consistent with our findings.

CONCLUSIONS

In conclusion, blue light and SNP were found to improve the quantitative and qualitative traits of the cut alstroemeria flowers. Among blue light durations, 12 h treatment extended the vase life of cut alstroemeria by 3 days as compared with the control. Also, 10 mg l^{-1} of SNP prolonged the longevity of cut alstroemeria by 3 days as compared with the control flowers. It is evident that blue light exposure for 12 h had an effect similar to the application of 10 mg l^{-1} SNP. Blue light exposure is, thus, recommended as a physical technique to prolong vase life and improve postharvest quality of cut alstroemeria 'Napoli' flowers.

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