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Effect of Blue Light Irradiation and Silver Nanoparticles at Different Rates on the Vase Life and Traits Involved in Postharvest Quality Preservation of Cut Alstroemeria cv. 'Napoli'

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Abstract

The application of blue light to postharvest cut flowers is a new method to improve their vase life. This research aimed to explore the effect of blue light irradiated for different times (6, 12, 18, or 24 hours) and the pulse treatment of silver nanoparticles (SNP) (5, 10, 15, or 20 mg L^{-1}) on the vase life and the related traits of cut *Alstroemeria* cv. 'Napoli' flowers. The control plants were treated with 3% sucrose. The study was based on a completely randomized design with three replications. The results showed that the longest vase life was 22.66 days obtained from 10 mg L^{-1} SNP, which did not differ significantly from the treatments of 12 hours of blue light irradiation (22.00 days) and 20 mg L^{-1} SNP (21.66 days). The lowest fresh weight losses were observed in the treatments of blue light for 18 and 12 hours and SNP at the rate of 10 mg L^{-1}, respectively. The highest dry matter percentage (57.34 %) was related to the plants treated with 10 mg L^{-1} SNP. The flowers irradiated with blue light for 12 hours had the highest chlorophyll a and b (2.52 and 1.27 mg g^{-1} FW, respectively), the highest catalase activity (5.26 nmol g^{-1} FW min^{-1}), and the lowest polyphenol oxidase activity (0.007 µmol g^{-1} FW min^{-1}). The lowest vase solution bacterial population was obtained from the application of 15 mg L^{-1} SNP and the highest petal protein from the irradiation of blue light for 24 hours. SNP was effective in controlling Gram-negative bacteria, and blue light was effective in controlling Gram-positive bacteria in the vase solution. It is inferred from the results that blue light, as a physical factor, is effective in preserving the vase life and relevant traits in the cut *Alstroemeria* 'Napoli' flowers.

Keywords: Antioxidant enzymes, Chlorophyll, Detection of bacteria strains, Polyphenol oxidase, Vase solution, Yeast.

INTRODUCTION

Alstroemeria (*Alstroemeria hybrida*) is an important cut flower with a high potential for supply in global markets. Like most cut flowers, the vase life of cut *Alstroemeria* flowers is reduced by water stress due to vascular blockage. The activity of microorganisms in vase solution and stem ends induces early aging and withering by causing water stress and stimulating ethylene synthesis, thereby reducing the marketability of these cut flowers (Edrisi, 2009; Chanasut *et al*., 2003). So, the inhibition of early aging and the improvement of postharvest longevity of cut *Alstroemeria* by physical and chemical methods can be effective in preserving their marketability and increasing their commercial value.

There are various methods to retain the vase life of cut flowers. One of the most effective ways is to use vase solutions that contain disinfectants and anti-ethylene compounds. The application of silver (Ag)-containing compounds as a disinfectant in vase solutions has long been interested due to their inhibitory effects on a wide range of microorganisms. In addition to the antibacterial effect, Ag ions have an anti-ethylene activity, too (Navarro *et al*., 2008). Researchers report that Ag ions in the preservative solution of cut flowers act as a strong antibacterial and anti-ethylene compound and contribute to preserving quality and extending postharvest shelf life (Halvey and Mayak, 2003). Silver nanoparticles (SNPs) contain Ag ions in very tiny dimensions and high contact areas, so they have stronger and more effective antimicrobial activity than Ag salts, which used to be used in vase solutions (Maneerung *et al*., 2008; Solgi *et al*., 2009, 2011). The positive impact of SNP in preventing water stress and preserving postharvest longevity has been reported for cut carnation (Halvey and Mayak, 2003; Lin *et al*., 2019b) and cut gerbera (Solgi *et al*., 2009).

The blue light (400-500 nm) is a vital environmental factor for plants as it is involved in a wide range of processes including growth, development, and flowering, stomatal opening and closure, resistance to pathogens, and the biosynthesis of pigments, flavonoids, and ethylene (Lin, 2000; Shi *et al*., 2014). There is not enough information about the effect of light on the postharvest life and quality of cut flowers. But, the blue light has recently been used to extend the postharvest shelf life of fruits. Most studies on blue light irradiation have mentioned it as a useful technique for increasing the nutritional and commercial value of fruits (Alferez *et al*., 2012; Shi *et al*., 2014).

There are reports about the role of blue light in improving the sugar and starch content of grapes (Poudel *et al*., 2008), increasing anthocyanin and accelerating the maturity of strawberries (Choi et al., 2015), reducing postharvest decay of citrus (Alferez *et al*., 2012; Liao *et al*., 2013), and retarding ethylene peak and increasing total dissolved solids in peaches (Gong et al., 2015). But, the effect of blue light on postharvest cut *Alstroemeria* flowers has not been studied yet. So, the present research aimed to shed light on the effects of blue light irradiation (470 nm) and the pulse treatment of SNP on the vase life, the number and species of microbes in vase solution, and the activity of catalase and polyphenol oxidase enzymes in the cut flowers of *Alstroemeria* cv. 'Napoli'.

MATERIALS AND METHODS

To study the effects of blue light irradiation and pulse treatment of SNP on the postharvest longevity of cut *Alstroemeria* cv. 'Napoli' flowers, an experiment was conducted on the basis of a completely randomized design with nine treatments and three replications. The same cut *Alstroemeria* cv. 'Napoli' flowers were transferred to the laboratory at the commercial harvest stage in commercial packages in the shortest possible time. In the laboratory, they were re-cut to a height of 40 cm under tap water and were used for the application of the treatments.

The treatments included exposure to blue light for 6, 12, 18, or 24 hours and the pulse treatment of SNP at a rate of 5, 10, 15, or 20 mg L^{-1}, as well as a control treatment (3% sucrose with no SNP and no blue light irradiation). The blue light with a wavelength of 470 nm was supplied by blue talc sheets (Fig. 1).

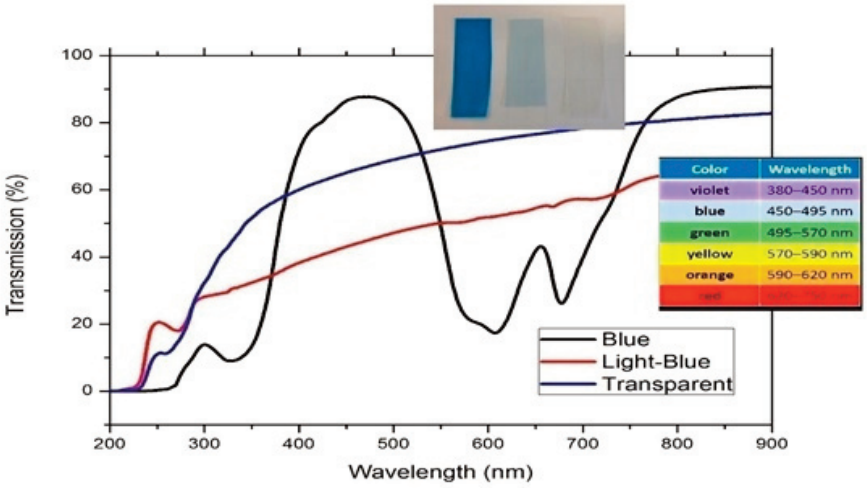

Fig. 1. The wavelength emitted from the talc sheets used to create the blue light.

SNP was purchased from Iranian Nano Material Co. and was applied at the target rates as the 24-h pulse. The permanent preservative solution was 3% sucrose. The treated flowers were kept in the laboratory at 20 ± 2 °C and 60-70 % relative humidity until the end of the experiment. The light intensity applied to the SNP-treated and control flowers was 15 μmol^{-1} m^2 s^{-1} irradiated for 12 hours during the day.

MEASUREMENT OF TRAITS

Vase life

It was calculated by counting the number of days from the treatment of the cut flowers with blue light and SNP until 50% shedding of the petals (Mutui *et al*., 2006).

Fresh weight loss

The fresh weight of a flower was determined with a 0.001-g digital scale on the first and last day of the experiment. The stem end recuts, which were performed to prevent vascular blockage, were also weighed. Then, the total fresh weight of the flower on the last day plus the weight of daily recuts was subtracted from the fresh weight on the first day, and the result was reported as the amount of fresh weight loss.

Dry matter

At the end of the vase life, a flower was weighed from each replication to find its fresh weight. Then, the same flower was dried in an electric oven at 105°C for 24 hours. Dry matter percentage was obtained from the following equation (Dashtbany *et al*., 2015):

$$\text{Dry weight (\%)} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

Chlorophyll a and b

Once the first symptoms of withering were observed in the room, the leaves were sampled and extracted using 80% acetone. Then, its absorbance was read at 643 and 660 nm with an APEL PD-103 UV spectrophotometer. Then, the following equations were applied to determine chlorophyll *a* and *b* (Mazumdar and Majumdar, 2003):

$$\text{Chlorophyll a} = 9.93\ (A_{660}) - 0.777\ (A_{643})$$
$$\text{Chlorophyll b} = 17.6\ (A_{643}) - 2.81\ (A_{660})$$

Total protein

When the first symptoms of withering appeared in the room, the petals were sampled and their total protein content was determined by the indirect Kjeldahl method. So, first, nitrogen percentage and then, total protein was determined by the following equations:

$$\text{Nitrogen (\%)} = 0.56 \times t \times (a - b) \times \frac{V}{W} \times \frac{100}{\text{D. M.}}$$

in which t is the concentration of the acid used for titration in mol L^{-1}, a is the amount of acid used for the sample in ml, b is the amount of acid used for the control in ml, V is the volume of the extract derived from digestion in ml, W is the plant sample weight for digestion in g, and D.M. is the plant dry matter percent.

Total protein (%)=nitrogen ×6.25

Vase solution bacteria count and detection

Twenty-four hours after the treatments, the vase solutions were sampled at a rate of 5 ml. Then, it was diluted with 0.9% saline normal serum in a completely sterilized environment. At the next step, 0.1 ml of the solution was cultured on a plate count agar. After 24 hours at 30°C, the bacteria colonies were counted with an optical microscope (Liu *et al*., 2009).

Then, the colonies were studied based on their morphology and the colonies with different morphologies were randomly selected for further investigation including morphological and biochemical tests, e.g., stainability and morphological traits in Gram staining, colony growth and morphology in MacConkey agar environment, mobility, oxidase and catalase production, gelatin hydrolysis, starch hydrolysis, indole production, urease production, methyl red reaction, acetoin production (VP), use of citrate, nitrate reduction, and H_2S production. Finally, the genera of the dominant bacteria were reported.

Catalase (CAT) and polyphenol oxidase (PPO) activity

To measure the CAT and PPO activity, an enzymatic extract was first prepared for which the petals were extracted using 50 mmol potassium phosphate buffer. The resulting extract was centrifuged at 10500 rpm at 4°C for 25 minutes. A sampler was, then, employed to separate the transparent supernatant, which was then used as the enzymatic extract.

The CAT activity was determined by Beers and Sizer's (1952) method. The reaction mixture included 40 µl of enzymatic extract, 400 µl of 15 mmol hydrogen peroxide, and 2.6 mmol of 50 mmol potassium phosphate (pH = 7). The CAT activity was determined at 240 nm with a Japanese V530 JASCO spectrophotometer using a distinction coefficient of 39.4 mmol cm^{-1}.

To measure PPO activity, a mixture was prepared composed of 300 µl of enzymatic extract, 2.5 ml of potassium phosphate buffer (pH = 7), 200 µl of 0.02 mol pyrogallol. Then, the sample absorbance was read at 420 nm with the Japanese V530 JASCO spectrophotometer and reported as the enzyme activity (Nicoli *et al*., 1991).

Statistical analysis

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

RESULTS

Vase life

The effects of blue light irradiation and SNP pulse treatment were significant ($P<0.01$) on the vase life of the *Alstroemeria* 'Napoli' cut flowers (Table 1). The most successful treatment in

preserving vase life was 10 mg L^{-1} SNP (22.66 days), but it did not differ from the blue light irradiation for 12 hours (22.00 days) and 20 mg L^{-1} SNP (21.66 days) significantly. The shortest vase life was observed in the control (19.00 days) and the blue light irradiation for 6 hours (19.50 days), not differing from one another significantly (Fig. 2).

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

S.o.V	df	Vase life	Fresh weight loss	Dry matter	Chloro-phylla	Chloro-phyll b	Total protein	Bacterial Pop-ulation invase solution	CA Tactivity	PP Oactivity
Treatment	8	4.64**	8.56**	49.9*	0.776**	0.615**	21.5*	4133**	3.14**	0.00007**
Error	16	0.377	1.019	17.23	0.136	0.1347	7.250	753.21	0.5694	0.00
CV (%)		2.94	47.01	8.05	21.72	20.08	11.41	42.49	23.66	11.18

* and **: Significant at P<0.05 and P<0.01, respectively.

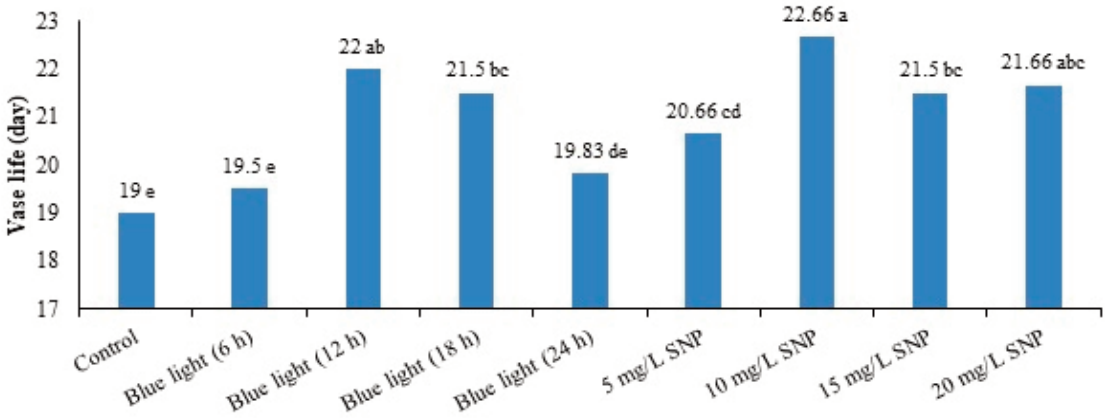

Fig. 2. The effect of blue light irradiation and SNP pulse treatment on the vase life of cut *Alstroemeria* 'Napoli' cut flowers.

Fresh weight loss

The effects of the experimental treatments were significant (P < 0.01) on fresh weight loss (Table 1). All treatments inhibited the fresh weight loss of the *Alstroemeria* 'Napoli' cut flowers versus the control (5.70 g). The lowest fresh weight loss was related to the flowers irradiated with blue light for 18 hours (0.53 g) and 12 hours (0.73 g), not differing significantly from the treatments of 10 mg L^{-1} SNP (0.93 g) and 15 mg L^{-1} SNP (1.48 g) (Fig. 3).

Dry matter

All experimental treatments increased the dry matter of the *Alstroemeria* 'Napoli' cut flowers significantly (P < 0.05) versus the control (Table 1). The control had the lowest dry matter of 44.54 % among all treatments. The highest dry matter (57.34 %) was obtained from the flowers treated with 10 mg L^{-1} SNP, which did not differ from that of the plants irradiated with blue light at all levels and those treated with 5 and 15 mg L^{-1} SNP significantly (Fig. 4).

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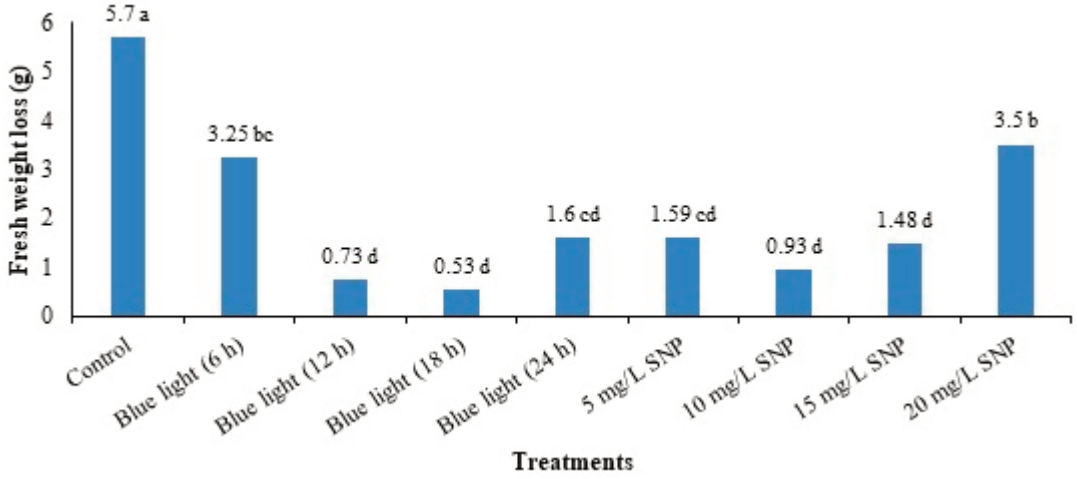

Fig. 3. The effects of blue light irradiation and SNP pulse treatment on fresh weight loss of the *Alstroemeria* 'Napoli' cut flowers.

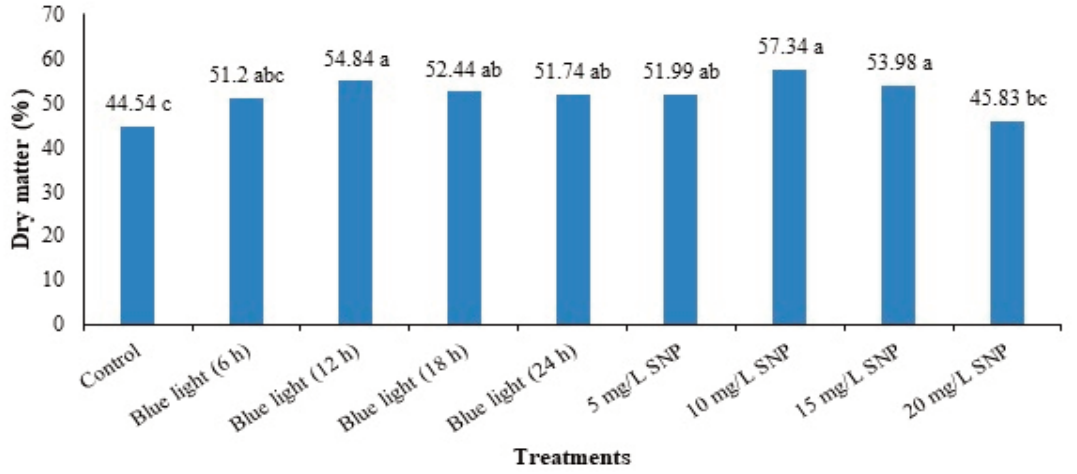

Fig. 4. The effects of blue light irradiation and SNP pulse treatment on dry matter percentage of the *Alstroemeria* 'Napoli' cut flowers.

Chlorophyll a and b

Blue light and SNP significantly ($P<0.01$) influenced chlorophyll a and b (Table 1). As is observed in Fig. 5, the lowest chlorophyll a (1.07 mg g^{-1} FW) was related to the control, but it did not differ from the treatments of blue light irradiation for 6, 18, and 24 hours and 20 mg L^{-1} SNP significantly. The plants irradiated by blue light for 12 hours had the highest chlorophyll a content of 2.52 mg g^{-1} FW, but they did not differ from the plants treated with 10 or 15 mg L^{-1} SNP significantly (Fig. 5).

Fig. 6 displays the effect of the experimental treatments on chlorophyll b content. It is evident that chlorophyll b content was increased with the application of all experimental treatments versus the control (0.58 mg g^{-1} FW). The highest chlorophyll b content of 1.27 mg g^{-1} FW was related to the treatment of blue light irradiation for 12 hours, which was in the same statistical group of the treatments of 5, 10, and 20 mg L^{-1} SNP (Fig. 6).

Total protein

The effects of the experimental treatments were significant ($P < 0.05$) on the total protein

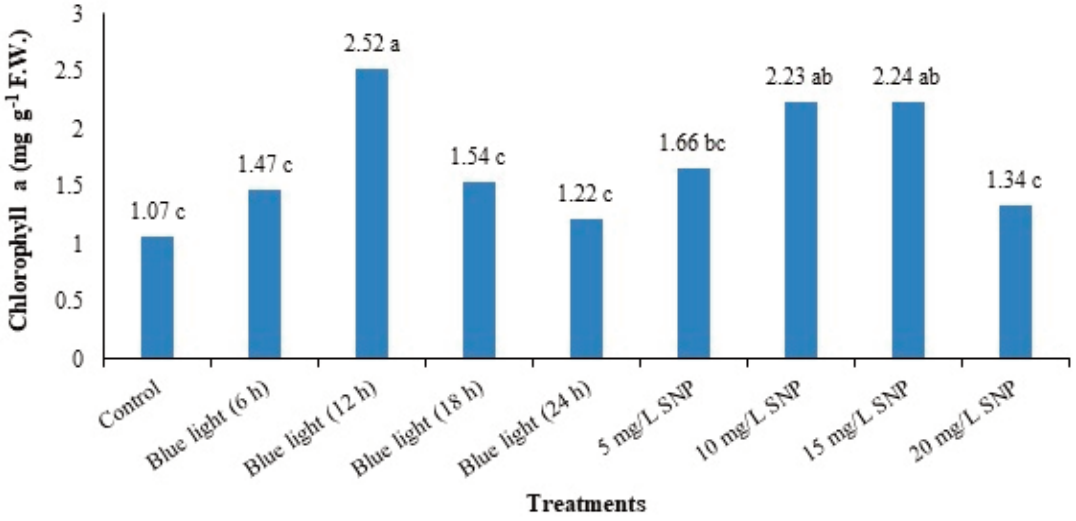

Fig. 5. The effect of blue light irradiation and SNP pulse treatment on the chlorophyll *a* content of the *Alstroemeria* 'Napoli' cut flowers.

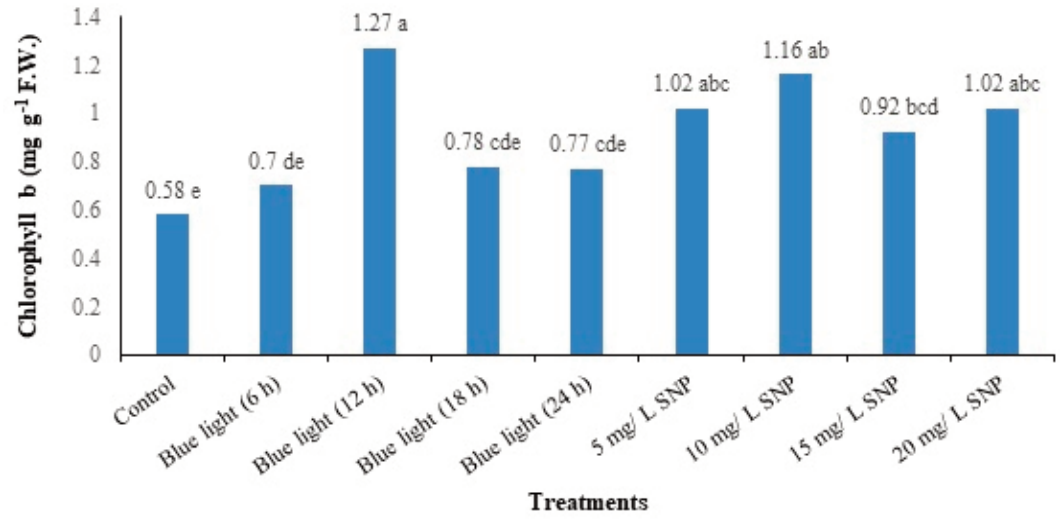

Fig. 6. The effect of blue light irradiation and SNP pulse treatment on the chlorophyll b content of the *Alstroemeria* 'Napoli' cut flowers.

content of petals (Table 1). The application of blue light and SNP increased total protein versus the control (16.15 %). Fig. 7 depicts that the highest total protein content of 25.63 % was obtained from the flowers treated with blue light for 24 hours, but it did not exhibit significant differences from that of the plants irradiated with blue light for 12 or 18 hours or those treated with SNP at a rate of 5, 10, 15, or 20 mg L^{-1}.

Population and strains of vase solution bacteria

The blue light and SNP were found to reduce vase solution bacterial significantly at the $P<0.01$ level (Table 1). According to Fig. 8, the control had the most number of vase solution bacteria with 123 colonies among all treatments. As the duration of blue light irradiation and the concentration of SNP were increased, the bacteria colonies were decreased. The least number of bacteria colonies was obtained from the treatment of 15 mg L^{-1} SNP (22.6 Log_{10} CFU ml^{-1}) among different

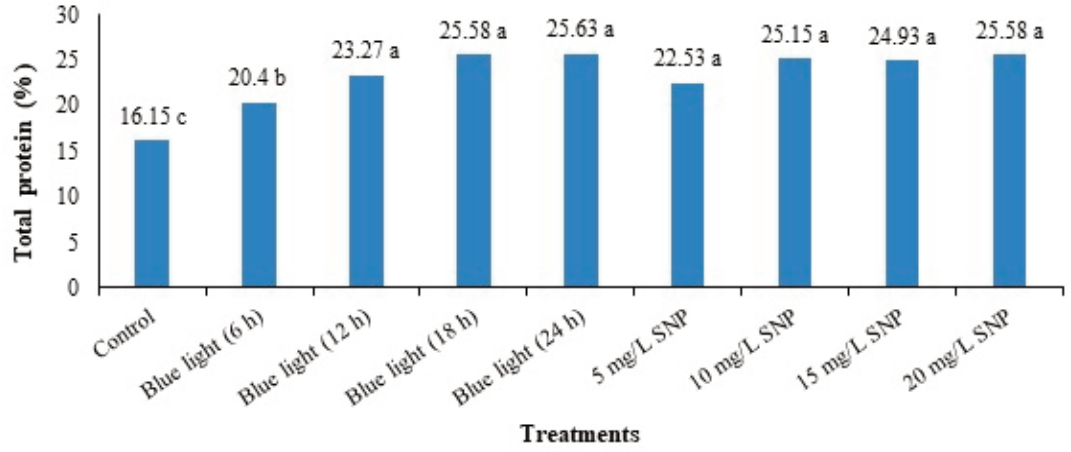

Fig. 7. The effect of blue light irradiation and SNP pulse treatment on the total protein content of the *Alstroemeria* 'Napoli' cut flowers.

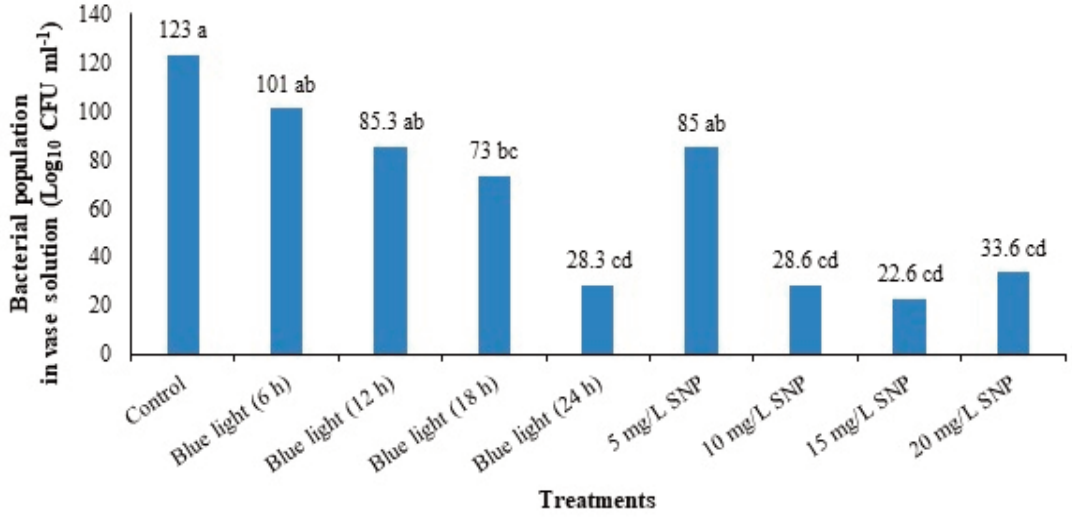

Fig. 8. The effect of blue light irradiation and SNP pulse treatment on the vase solution bacteria of the *Alstroemeria* 'Napoli' cut flowers.

levels of SNP and from the irradiation of blue light for 24 hours (28.3 Log_{10} CFU ml^{-1}) among different levels of blue light irradiation, which was found to be the most effective treatment along with 10 mg L^{-1} SNP (28.6 Log_{10} CFU ml^{-1}) in reducing vase solution bacteria population (Fig. 8).

Table 2 presents the strains of the bacteria detected in the vase solution of the cut Alstroemeria flowers. As is seen, strains of Gram-negative and Gram-positive bacteria, as well as yeasts, were recorded in the control treatment. When SNP was applied, the growth of Gram-negative bacteria was perfectly stopped in the vase solution. Yeast growth was only observed in the treatment of 10 mg/l SNP. The bacteria from the genera of *Bacillus*, *Staphylococcus*, and *Clostridium* were among the strains detected in the vase solution containing different levels of SNP. Among different levels of blue light, irradiation for 6 and 18 hours inhibited the growth of Gram-positive bacteria in the vase solution, and yeast growth was stopped in the vase solutions irradiated by blue light for 12, 18, and 24 hours. In general, it can be claimed that SNP was effective in suppressing Gram-negative bacteria and blue light irradiation (especially 6 and 18 hours) was effective in inhibiting Gram-positive bacteria in the vase solution (Table 2).

Catalase (CAT) activity

CAT activity was significantly (P<0.01) influenced by the experimental treatments (Table 1). CAT activity was increased by the application of all treatments versus the control (2.23 nmol g^{-1} FW min^{-1}) except for the duration of 6 hours. The highest CAT activity was 5.26 nmol g^{-1} FW min^{-1} related to the flowers irradiated with blue light for 12 hours, which did not differ from those treated with 10 mg/l SNP (3.98 nmol g^{-1} FW min^{-1}) significantly (Fig. 9).

Polyphenol oxidase (PPO) activity

The effects of blue light irradiation and SNP were significant (P < 0.01) on PPO activity (Table 1). Based on the comparison of means, the PPO activity was the highest in the control (0.024 µmol g^{-1} FW min^{-1}) and the treatment of blue light for 6 hours (0.021 µmol g^{-1} FW min^{-1}). The best treatments in reducing PPO activity were blue light irradiation for 12 hours (0.007 µmol g^{-1} FW min^{-1}) and 10 mg L^{-1} SNP (0.013 µmol g^{-1} FW min^{-1}) (Fig. 10).

Table 2. The general of the bacteria detected in the vase solution of the *Alstroemeria* 'Napoli' cut flowers.

Treatments	Gram-negative bacteria	Gram-positive bacteria	Fungus
Control	*E. coli, Pseudomonas*	*Bacillus, Enterococcus*	Yeast
5 mg L^{-1} Nanosilver	-	*Bacillus, Clostridium, Staphylococcus*	-
10 mg L^{-1} Nanosilver	-	*Bacillus, Staphylococcus*	Yeast
15 mg L^{-1} Nanosilver	-	*Bacillus, Clostridium*	-
20 mg L^{-1} Nanosilver	-	*Bacillus, Clostridium*	-
blue light (6 h)	*E. coli, Enterobacter*	-	Yeast
blue light (12 h)	*E. coli*	*Staphylococcus*	-
blue light (18 h)	*E. coli*	-	-
blue light (24 h)	*E. coli*	*Clostridium*	-

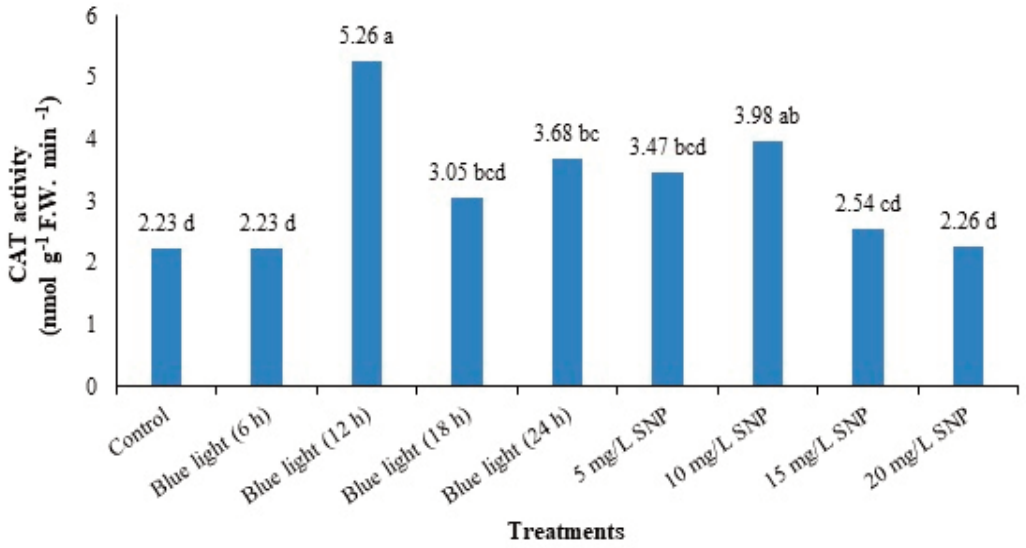

Fig. 9. The effect of blue light irradiation and SNP pulse treatment on the catalase (CAT) activity in the *Alstroemeria* 'Napoli' cut flowers.

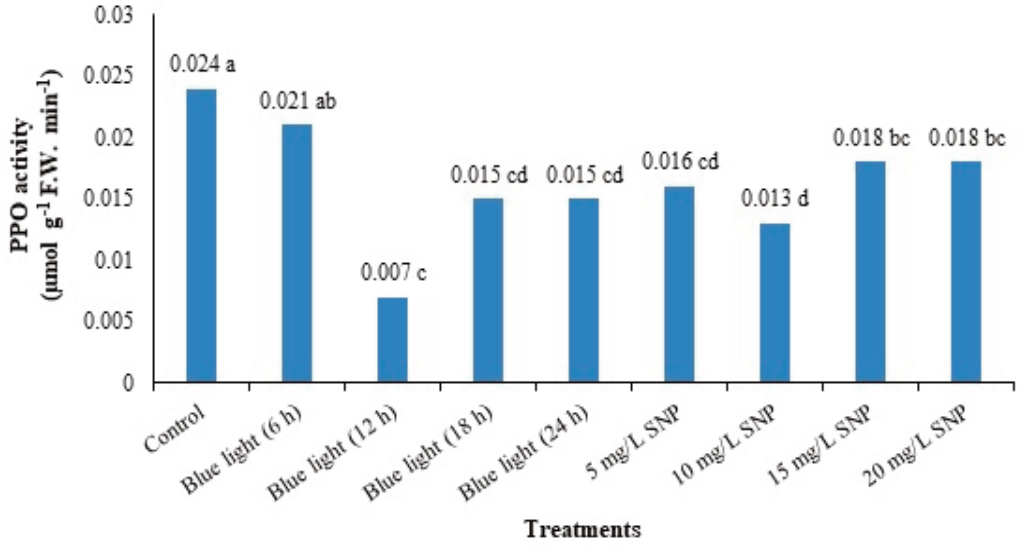

Fig. 10. The effect of blue light irradiation and SNP pulse treatment on the polyphenol oxidase (PPO) activity in the *Alstroemeria* 'Napoli' cut flowers.

DISCUSSION

The accumulation and activity of microorganisms in vase solutions and stem ends are the most common cause of vascular blockage and the reduction of postharvest longevity of cut flowers. In addition to vascular blockage and the induction of water stress, microorganisms are reportedly involved in the production of toxic compounds and ethylene and the acceleration of the aging process (van Doorn, 2012; Fazlalizadeh *et al*., 2013).

SNP is a strong antimicrobial compound whose application in cut flower preservative solutions inhibits the destructive activity of microorganisms. Researchers argue that Ag ions disrupt the functioning of bacteria and kill them by disordering cellular respiration and destroying cell walls. So, Ag in vase solutions hinders vascular blockage by reducing bacterial load and contributes to the freshness and the extension of vase life by helping the retention of water uptake (Lin *et al*., 2019 a,b; Ershad Langroudi *et al*., 2019). There are reports about the positive effect of SNP on preserving freshness and extending postharvest longevity of cut carnation 'Master' (Liu *et al*., 2014) and gladiolus 'Eerde' (Li *et al*., 2017), which is consistent with our findings.

In the present research, the application of SNP reduced the bacterial load of the vase solution and inhibited the loss of fresh weight, thereby contributing to the preservation of dry matter and the extension of vase life of the *Alstroemeria* 'Napoli' cut flowers, which was quite expected given the antimicrobial effect of SNP. van Doorn (2012) suggests that the effect of SNP on increasing water uptake by cut flowers is related to its role in reducing the growth of microorganisms and the conservation of the stem's hydraulic conductivity. Since water uptake has a direct relationship with the conservation of cell turgor and fresh weight, the positive effect of SNP on preserving and increasing fresh weight and dry matter is reasonable. Li *et al*. (2019b) reported that the pulse application of 15 mg/l SNP resulted in an increase in water uptake, the conservation of fresh weight, and a delay in the withering of cut Gardenia flowers. The favorable effect of SNP has been reported in reducing bacterial load, increasing water uptake, keeping freshness, and extending vase life of cut gladiolus (Li *et al*., 2017) and *Alstroemeria* (Ershad Langroudi *et al*., 2019), which agrees with our findings.

Naing *et al*. (2017) showed that the treatment of cut carnation flowers with SNP at a rate of 25 or 50 mg L^{-1} stopped bacteria production versus the control. The most abundant bacterium

in Naing *et al.*'s (2017) study was a strain of *E. coli*. In the present work, the application of SNP inhibited the growth of Gram-negative bacteria and only Gram-positive bacteria (*Bacillus*, *Clostridium*, and *Staphylococcus*) were observed in the SNP-containing vase solution. Zagory and Reid (1986) detected *Fluorescent Pseudomonad* and *Nonfluorescent Pseudomonad* in the vase solution of roses 'Cara Mia'.

Dry matter escalation in cut flowers is one of the consequences of applying disinfectants to vase solutions. Indeed, when a disinfectant is applied to the vase solution, water is taken up according to the plant's requirement. This factor increases flower fresh weight and carbohydrate synthesis in plant tissues, which subsequently increases the dry matter of the cut flower. This has been supported by numerous researchers (Blankenship and Dole, 2003; Elgimabi and Ahmed, 2009; Hashemabadi *et al.*, 2014).

Leaf aging is principally accompanied by chlorophyll loss and degradation. In cut *Alstroemeria* flowers too, leaf yellowing is a symptom showing the initiation of aging and chlorophyll degradation (Ferrante *et al*., 2002). The presence of chlorophyll in plant tissues indicates that the cells are active and produce sugar. Sugar decelerates aging by adjusting cell respiration and osmotic pressure (Tanazad *et al*., 2016). Researchers argue that ethylene sensitivity is a reason for the chlorophyll loss of leaves. They suggest that ethylene results in the translocation and mobilization of chlorophyll and increases the aging rate in plant tissues (Lentini *et al*., 1988). In the present work, the treatment of the cut *Alstroemeria* flowers with SNP increased their chlorophyll a and b content versus the control. Many researchers have attributed the better performance of disinfectants in preserving leaf pigments to their capability of reducing bacteria load and improving postharvest water relations. Since leaf color has a direct relationship with the carbohydrate content of leaf tissues, it can be said that disinfectants contribute to maintaining cell turgor and health and preventing pigment degradation by reducing water stress (Edrisi, 2009; Hassanpour Asil and Karimi, 2010; Hashemabadi *et al*., 2014).

The protein content of flowers starts to fall sharply once they are harvested from their maternal plants. There is a direct relationship between aging and protein degradation (Lerslerwong *et al*., 2009; Zhao *et al*., 2018). Total protein declines during aging due to an increase in the activity of proteases and a decrease in protein synthesis (Brady, 1988; van Doorn and Stead, 1997). It is, therefore, possible to help the preservation of membrane structure and proteins by reducing stress and maintaining cell turgor, which will delay plant tissue aging and death (Sood and Nagar, 2003; Lerslerwong *et al*., 2009). As was already mentioned, SNP was involved in preserving the protein content of the cut *Alstroemeria* flowers.

Aging is the result of the production of reactive oxygen species (ROS) and the oxidative processes in plant tissues. There are reports that as aging is accelerated in plant tissues, free oxygen radicals are continuously produced at a high rate, resulting in an increase in the accumulation of O_2, H_2O_2, and MDA in plant tissues. Membrane permeability increases with the initiation of aging so that membrane integrity is lost over time, ultimately leading to cell death (Ohe *et al*., 2005; Kumar *et al*., 2010; Xia *et al*., 2017). Antioxidant enzymes, e.g., SOD, POD, and CAT, suppress the activity of free radicals during aging (Xu et al., 2014). Indeed, antioxidant enzymes reduce the aging and withering of cut flowering by suppressing ROS and reducing the damages of stressful factors (Palma *et al*., 2002; Tanazad *et al*., 2016).

In the present study, CAT activity was increased at all four levels of SNP versus the control. Mortazavi *et al*. (2007) state that the increased activity of CAT prevents early aging of petals. Li *et al*. (2010) reported that SNP application increased CAT activity. Similar results were reported by Zhao *et al.* (2018) for cut *Paeonia lactiflora* flowers, which agrees with our findings.

PPO is a robust oxidating factor that causes the decay and brown color of petals and fruits by oxidizing phenols. So, postharvest longevity can be extended by reducing the activity of this

enzyme. The inhibition of PPO activity is, thus, of crucial importance for postharvest maintenance of flowers and fruits (Dubravina *et al*., 2005). In the present study, SNP and blue light reduced the activity of the PPO enzyme, which was expected given its positive effect on reducing stress and increasing the activity of antioxidant enzymes.

The present research was the first attempt to apply blue light to cut *Alstroemeria* flowers at the postharvest stage. Previous studies have focused on the effect of the postharvest blue light application on different fruits whose results have revealed the positive effect of this irradiation on the control of fungal infections and spoilage of the fruits during storage (Alferez *et al*., 2012; Liao *et al*., 2013). We observed that blue light irradiation reduced the bacteria load of the vase solution versus the control. The application of blue light for 6 or 18 hours stopped the growth of Gram-positive bacteria. Irradiation for 12, 18, or 24 hours stopped the growth of yeasts, and *E. coli* was the only Gram-negative bacteria detected in the vase solution. According to the results, SNP outperformed blue light in controlling Gram-negative bacteria. However, the application of blue light for 6 or 18 hours outperformed SNP in controlling Gram-positive bacteria. Liao *et al*. (2013) reported that blue light reduced postharvest spoilage of citrus. They stated that the spoilage control in the blue light-treated citrus was related to the effect of blue light on reducing the growth of microorganisms, inducing defensive responses in the host, and reducing the activity of cell wall digesting enzymes. A decrease was reported by Alferez *et al*. (2012) in the growth and activity of microorganisms in the blue light-treated tangerine at the postharvest stage, which is in agreement with our findings. Given the relationship of vase solution bacteria population with water uptake and the preservation of cell turgor, it can be said that the application of blue light contributed to conserving water uptake, fresh weight, and dry matter and consequently, increasing the vase life of the cut *Alstroemeria* flowers by reducing the bacteria load of the vase solution. Jerzy *et al*. (2011) found that the growth of chrysanthemums under blue light increased their vase life. Sedaghathoor (2015) studied the effect of wall color (blue, red, brown, and white) and SNP on the vase life of cut carnations and obtained the longest vase lives from the application of white light × 5 mg L^{-1} SNP (18.32 days) and blue light × 5 mg L^{-1} SNP (17.1 days).

Blue light irradiation is an effective technique to improve the color and commercial value of horticultural products (Yuan *et al*., 2017). We obtained the highest chlorophyll a and b contents from the application of blue light. Xu *et al*. (2014) found that the application of blue light during storage increased the activity of antioxidant enzymes in strawberries. This corroborates our findings for *Alstroemeria*. In general, it can be said that postharvest blue light irradiation contributed to conserving petal fresh and dry weight and proteins by increasing CAT activity, reducing the activity of destructive PPO enzyme, and reducing microorganisms of the vase solution and contributed to extending postharvest longevity of the cut *Alstroemeria* flowers by preventing stresses, e.g., water stress and oxidative stress. However, further research is required to understand the mechanism by which blue light improves these traits.

CONCLUSION

Blue light and SNP had positive effects on improving the quantitative and qualitative traits of cut *Alstroemeria* flowers. Among different levels of blue light, its irradiation for 12 hours extended vase life by three days versus the control. Also, among different levels of SNP, 10 mg L^{-1} was found to be the best rate for preserving vase life as the flowers treated with 10 mg L^{-1} SNP exhibited 3 days longer postharvest longevity. So, it can be concluded that the application of blue light for 12 hours had an effect similar to the application of 10 mg L^{-1} SNP, so blue light irradiation is recommended as a physical method to extend the vase life and postharvest quality of cut *Alstroemeria* 'Napoli' flowers.

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