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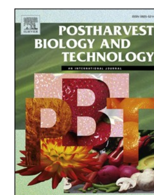

# Postharvest illumination of alstroemeria: Effect of light quality on flower metabolism and shelf life

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ABSTRACT

Despite the good postharvest performance of alstroemeria flowers, leaf yellowing is one of the most important signs of senescence and decay, as well as the flower size and time to abscission. In this work, we tested the effect of 50 μmol $m^{-2}$ $s^{-1}$ white (WL, broad spectrum) and red-blue (RBL, 40:60, 630 + 465 nm) light-emitting diodes on cut alstroemeria stored at 20 °C, or WL on cut alstroemeria stored at 5 °C, on postharvest flower quality and vase life. The light-treated floral stems had higher water consumption throughout storage compared to the controls stored in the dark, with no variation in stem diameter. The tepal area was increased by the light treatment at both storage temperatures. The leaf color remained similar to that at harvest in the light-treated flower stems (WL and RBL), while there was a strong yellowing in the controls stored in the dark. Anthocyanins increased mostly in flowers stored under WL, although this was more evident at 20 °C. WL treatment strongly slowed chlorophyll degradation and increased sugar content in leaves and tepals by 3.4 and 1.8 times, respectively, at 20 °C, and by 6 and 2.9 times, respectively, at 5 °C. The increase in sugar levels in light-treated flowers may have caused the tepal expansion but also delayed the onset of leaf senescence, and consequently the tepal abscission. The WL was the most effective storage condition not only to extend cut alstroemeria shelf life, but also to improve the postharvest flower quality, both at room temperature and under refrigeration.

## 1. Introduction

Despite the good flower vase life, leaf yellowing is often cited as a relatively early sign of senescence of alstroemeria cut flowers (Ferrante et al., 2002; Mutui et al., 2003) and, together with tepal abscission, limit postharvest performance. Postharvest issues can be reduced very significantly with cold storage (Zencirkiran and Mengüç, 2003). But since cold cannot be always guaranteed throughout the alstroemeria marketing chain, several postharvest chemical alternatives have been tested, such as hormonal treatments, alone or in combination with storage at low temperatures (Ferrante et al., 2002; Mutui et al., 2003; Bagheri et al., 2012), calcium chloride and sucrose (Galati et al., 2015), and, due to the sensitivity of alstroemeria to ethylene, applications of silver thiosulfate (Chanasut et al., 2003; Wagstaff et al., 2005) and 1-methylcyclopropene (Galati et al., 2017). Applications of thidiazuron alone delayed leaf yellowing (Ferrante et al., 2002), or added with benzyladenine to solutions containing sucrose also increased alstroemeria flower and leaf longevity (Hatamzadeh et al., 2012) The role of sugars, from photosynthesis or added to the vase solution, in the flower senescence has been questioned (van Doorn, 2008); however, it is evident that sugars influence the delay of senescence (Arrom and Munné-Bosch, 2012; Dar et al., 2014; Rabiza-Świder et al., 2020). On the other hand, for operational reasons and better post-harvest conservation, the contribution of sugars through preservative solutions is not the best alternative to lighting: if an excess of sugars comes from photosynthesis, the metabolism in the tissues is rearranged, but if it comes from an external supply (for example, sugar preserving solutions), it harms petals and leaves quality (Bieleski et al., 1992). Light cause an increase in the stomata conductance improving photosynthesis capacity, although in alstroemeria plants an increase of supplemental light intensity at values higher than 120 μmol $m^{-2}$ $s^{-1}$, reduced the light use efficiency (Trouwborst et al., 2015). The use of halogen high-intensity

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white light during storage combined with gibberellic acid has delayed leaf yellowing in alstroemeria cut flowering stems (Jordi et al., 1994). Because traditional light sources such as high-pressure sodium lamps do not allow to apply discrete bands and are not very efficient due to a high radiant heat generation, they are being replaced by light-emitting diodes (LEDs). Light quality can influence ethylene metabolism and the postharvest shelf life of cut flowers. Blue light decreased ethylene production and increased total chlorophyll in alstroemeria (Michalczuk et al., 1992; Anvari et al., 2022) and in carnation when it was compared to white or red light (Aalifar et al., 2020). Taking into account the discrepancy found in other works regarding the effect of the light quality on the shelf life of cut flowers, and seeking to broaden the knowledge on the effect of light in some physiological traits of cut alstroemeria, this work aimed to assess the effect of different light sources on postharvest quality of alstroemeria leaves and flowers stored at different temperatures.

## 2. Materials and methods

### 2.1. Plant material and storage conditions

Alstroemeria flowers (*Alstroemeria* × *hybrida* var. Hot Pepper, Könst Alstroemeria B.V., The Netherlands) were harvested in La Plata, Argentina. Stems were recut to 60 cm under water, to prevent embolism, and transferred to 1 L glass flasks filled up to 0.25 L with deionized water previously adjusted to pH 3.5 with citric acid. In the first experiment, flasks were transferred to a room kept at constant temperature and humidity conditions (20 ± 2 °C, 70 % ± 5 % RH) under three different conditions: storage in darkness (Control, < 1 μmol $m^{-2}$ $s^{-1}$, warm white LED illumination (WL, 430–730 nm, with peaks at 460 and 608 nm) or red-blue (40:60) LED illumination (RBL, 630 + 465 nm). Given that RBL treatment showed no general advantages over WL treatment at 20 ºC, it was not included in the second set of experiments performed at 5 °C. A second experiment was conducted under cold storage (5 ± 1 °C, 90 % ± 5 % RH) using WL for treatments and darkness for the controls. In both experiments (at 20 and 5 °C), the light illuminated the upper side of the flowers at 50 μmol $m^{-2}$ $s^{-1}$, with a light/dark period of 16/8 h. The emission spectrum (Suppl. Fig.) and light intensity were measured with a spectrometer (Avantes, The Netherlands). The stems were maintained in a constant solution volume by adding fresh acidified water on each sampling day. Flower samples were taken after 0, 7, and 14 d when stems were kept at 20 °C or after 0, 26, and 36 d when kept at 5 °C, and immediately analyzed or otherwise frozen in liquid nitrogen and stored at − 20 °C until use. Eighteen flowers were used for each treatment, with six flower stems per treatment per sampling day divided into 3 groups as biological replicates. The entire experiment was repeated two times both at 20 °C and 5 °C, to observe the visual appearance of treated flower stems.

### 2.2. Water consumption, stem diameter, and tepal area

To analyze the water status of the stems, the fresh weight and stem diameter were measured at 7 and 14 d, or at 26 and 36 d during storage at 20 or 5 °C respectively. The flasks were refilled with acidified water up to the previous level, and the replacement volume was recorded to estimate consumption via transpiration. Tepal area ($cm^2$) was measured with ImageJ 1.53 t software, at 7 and 14 d after harvest in flowers stored at 20 °C, and 26 and 36 d after harvest in flowers stored at 5 °C. For water consumption were taken 6 flower stems per treatment per sampling day, while for tepal area were measured 21 tepals per treatment per sampling day.

### 2.3. Leaf color

The leaf yellowing was determined in the upper, middle, and lower whorl of leaves. The color was evaluated by a colorimeter (Minolta CR-300) to obtain the L*, a*, and b* coordinates. Since a* was < 0 and b* was > 0, the hue angle was calculated as: °H = 180° + [360 * tan − 1 (b*/a*)/6.28]. Five color measures were done per flower stem, and 15 measures per treatment per sampling day.

### 2.4. Chlorophylls

Frozen leaves were immersed in liquid nitrogen to obtain a fine and uniform grinding. The tissue was ground, then 0.5 g of tissue was mixed with 5 mL of acetone and water (80:20). The homogenate was stirred for 2 min and centrifuged at 5000 × *g* for 15 min. The supernatant was collected, and the procedure was repeated to obtain additional pigment from the tissue. The supernatants were pooled, and total chlorophyll content was determined by spectrophotometry according to Lichtenthaler (1987) and expressed as μg $g^{-1}$ on a fresh weight basis. Three measurements were done per treatment and sampling date.

### 2.5. Sugar content

For leaves, approximately 10 g of frozen tissue was ground in a mill, and 0.8 g of the powder was homogenized with 10 mL of ethanol 96 %. The mixture was vortexed for 1 min and centrifuged at 5000 × *g* for 10 min. For flower tepals, 1 g of the ground tissue was homogenized with 10 mL of ethanol 96 %, following the same extraction procedure mentioned for leaf tissue. Total sugar content was measured with the anthrone method according to Hasperué et al. (2016). Three measurements were done per treatment and sampling date.

### 2.6. Hydrophilic and lipophilic antioxidants

#### 2.6.1. Hydrophilic antioxidants

For the hydrophilic antioxidant measurement, it was used the Folin-Ciocalteu reagent according to Singleton et al. (1999) with modifications. For the reaction mixture, 50 μL of plant tissue extract was added to 950 μL of distilled water and 50 μL of Folin-Ciocalteu reagent diluted 1:1 in water. After 3 min, 100 μL of 20 % (w/v) $Na_2CO_3$ in 0.1 M NaOH was added, and the resulting solution was incubated at 25 °C for 90 min. The absorbance was measured in a spectrophotometer at 760 nm. A standard curve with gallic acid (GA) was done, and results were expressed in mg $kg^{-1}$ on a fresh weight basis. Three measurements were done per treatment and sampling date.

#### 2.6.2. Lipophilic antioxidants

As the content of lipophilic antioxidants, we measured the total carotenoids given their importance in plant tissues. An acetone and water (80:20) extract was made as described in the Section 2.4, and total carotenoid content was determined by spectrophotometry according to Lichtenthaler (1987). Results were expressed as μg g-1 on a fresh weight basis. Three measurements were done per treatment and sampling date.

### 2.7. Total anthocyanins

The monomeric anthocyanins content was determined spectrophotometrically by the pH-differential method (Lee et al., 2005), which is based on the structural change of the anthocyanin chromophore between pH 1.0 and 4.0. Approximately 5 g of frozen red tepals (second tepal whorl) was immersed in liquid nitrogen, following ground in a mill, and then 0.5 g of the resulting powder was homogenized with 5 mL of potassium chloride buffer, 0.025 M, pH 1 (colored anthocyanin oxonium form), or with sodium acetate buffer, 0.4 M, pH 4 (colorless hemiketal anthocyanin form). The plant suspensions were vortexed and then centrifuged to obtain a translucent extract. Absorbance was measured at 520 nm and 700 nm (to correct for haze), and the anthocyanin content was calculated based on:

C3G (mg $L^{-1}$) = (Abs. pH:1 − Abs. pH:4,5) × $\varepsilon^{-1}$ × $cm^{-1}$ × DF (DF: dilution factor).

Total anthocyanin content was expressed as mg of cyanidin-3-glucoside(C3G) $L^{-1}$ (which is considered the major anthocyanin pigment of this plant tissue) using the corresponding extinction coefficient of $\mathcal{E} = 0{,}060$ L $mg^{-1}$ $cm^{-1}$. Three measurements were done per treatment and sampling date.

### 2.8. Statistical analysis

The experiments were designed according to a factorial design, with the factors as the illumination treatment (Control, RBL, and WL) and storage time at 20 °C (0, 7, or 14 d) or 5 °C (0, 26, or 36 d). Data were analyzed by ANOVA, and the means were compared by Fisher's LSD test using InfoStat software (Di Rienzo et al., 2012) at a significance level of $P < 0.05$.

## 3. Results

### 3.1. Light treatment performed at 20 °C

#### 3.1.1. Water consumption and tepal area

Water consumption was higher in the light-treated flowers throughout storage, reaching twice the accumulated levels at 14 d of storage compared to the controls (Fig. 1**A**). The increase in water consumption between 7 and 14 d of storage was not significant in the controls, but it was in the light treated flowers. All flowers reached the largest tepal size at 7 d, and the WL treatment promoted a greater increase in the tepal size, followed by the RBL treatment (Fig. 1**B**). Compared to the controls, after 7 d light treated flowers had tepals of almost 30 % and 20 % bigger for WL and RBL treatments, respectively. After the floral opening, there was a decrease in the tepal area. However, by day 14, the WL-treated flowers had tepals 14 % bigger than the controls. In the case of the control flowers, the tepals at 14 d were similar to those at day 7.

#### 3.1.2. Leaf color and total chlorophylls

In the flowers stored in the dark, a marked yellowing was observed during storage, with a sustained increase in the L* parameter and a decrease in hue (Fig. 2). After 14 d of storage, these samples completely lost their commercial quality. In WL and RBL treated stems high visual quality was extended at least for seven days. Both during and at the end of storage, there was almost no difference in color between WL and RBL treatments, and at 14 d of storage, flowers had a commercially acceptable quality, with L* values of 42 compared to the controls with L* of 65 (Fig. 2**B**). The difference in the quality of the light treated floral stems was, in turn, complemented by less tepal abscission (data not shown).

Chlorophylls decreased throughout storage in all stems. However, a significant delay in chlorophyll degradation was observed in the floral stems stored illumination (Fig. 2**D**). Chlorophyll loss during the first seven storage days was slower in light-treated flowers, 10 % for RBL and 19 % for WL, while it was 50 % in the controls. At 14 d the differences between the light-treated flowers and the controls were evident, with chlorophyll contents 123 % and 162 % higher with respect to controls in the RBL and WL flowers, respectively. Comparing between light treatments, the decrease in the chlorophyll content from 7 to 14 d was more pronounced in the floral stems treated with RBL than in those treated with WL, which ended the storage period with the highest chlorophyll content.

#### 3.1.3. Sugar content

There was a substantial accumulation of sugars in the light-treated flower stems, and the highest sugar content was measured at 14 d. On the contrary, a decrease in sugars was observed in the controls during storage, mainly in leaves. In WL leaves, the sugar content increased during the storage period, while the RBL leaves showed differences with the controls only towards day 14 (Fig. 3**A**). In the case of tepals, there was an increase in sugars during storage in all light treated flowers, and this increase was higher in the WL ones, which had higher sugar levels

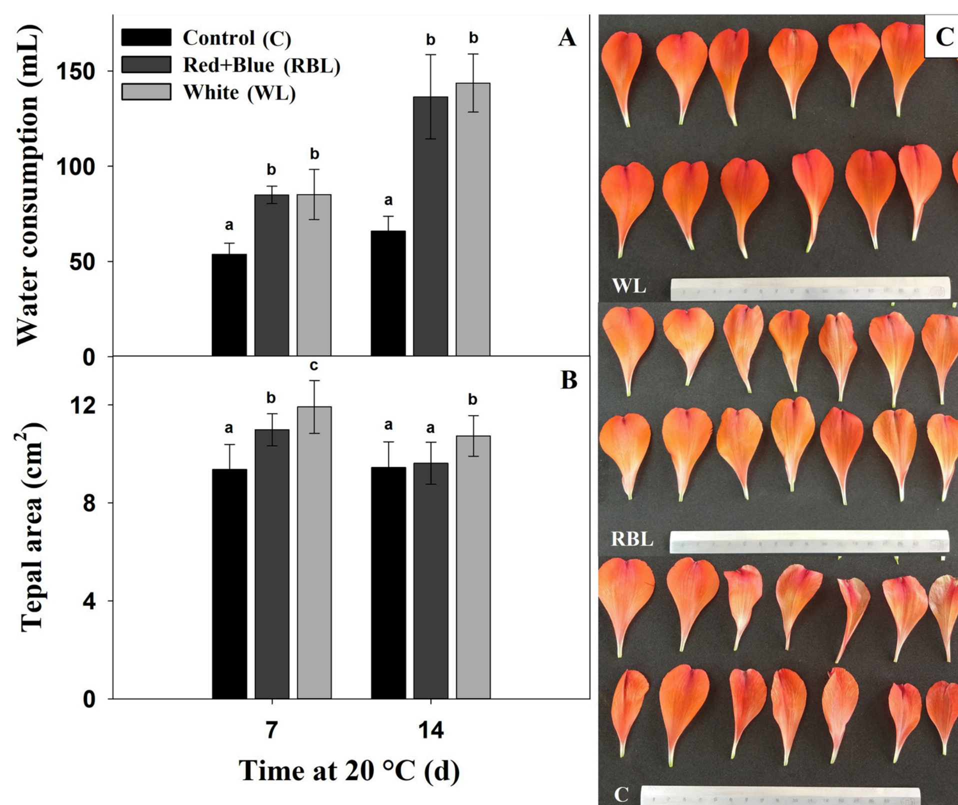


**Fig. 1.** Water consumption of floral stems (a), tepal area (b), and flower tepals of alstroemeria (c) at 14 d of storage at 20 °C. Data represent means ± standard deviation. Different letters along a single storage day indicate significant differences based on the LSD test at a significance level of $P < 0.05$.

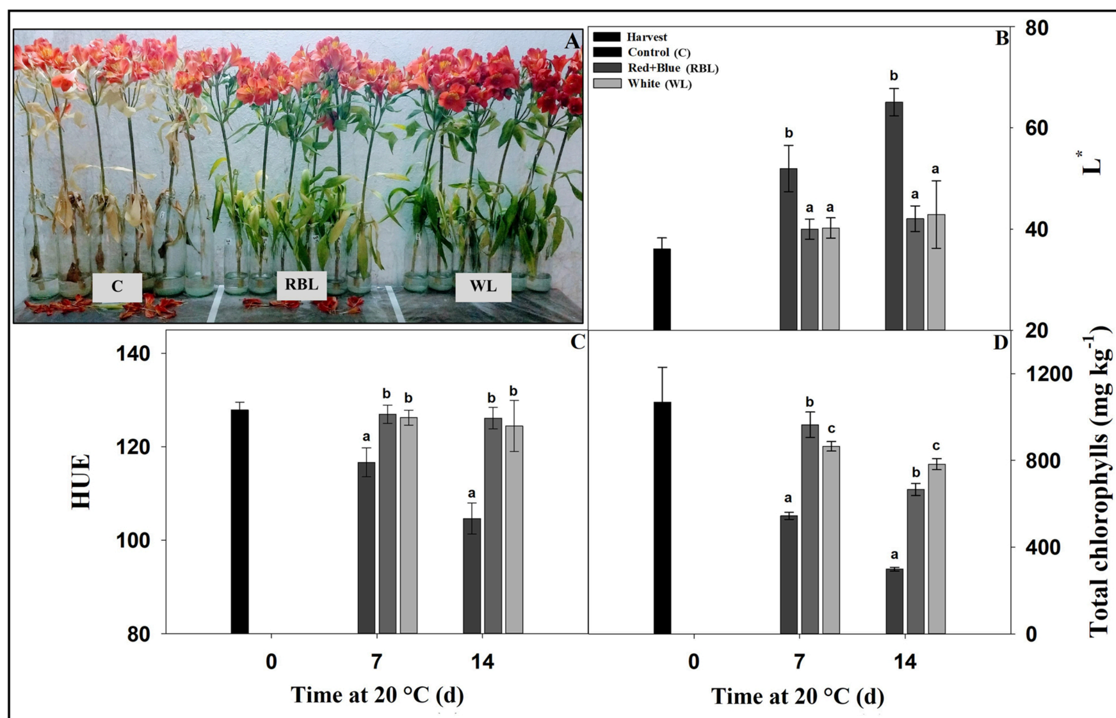


**Fig. 2.** Floral stems (**a**), color L* (**b**), hue (**c**) parameters, and total chlorophylls (a + b) (**d**) of alstroemeria leaves stored for 0, 7, or 14 d at 20 °C. Data represent means ± standard deviation. Different letters along a single storage day indicate significant differences based on the LSD test at a significance level of $P < 0.05$.

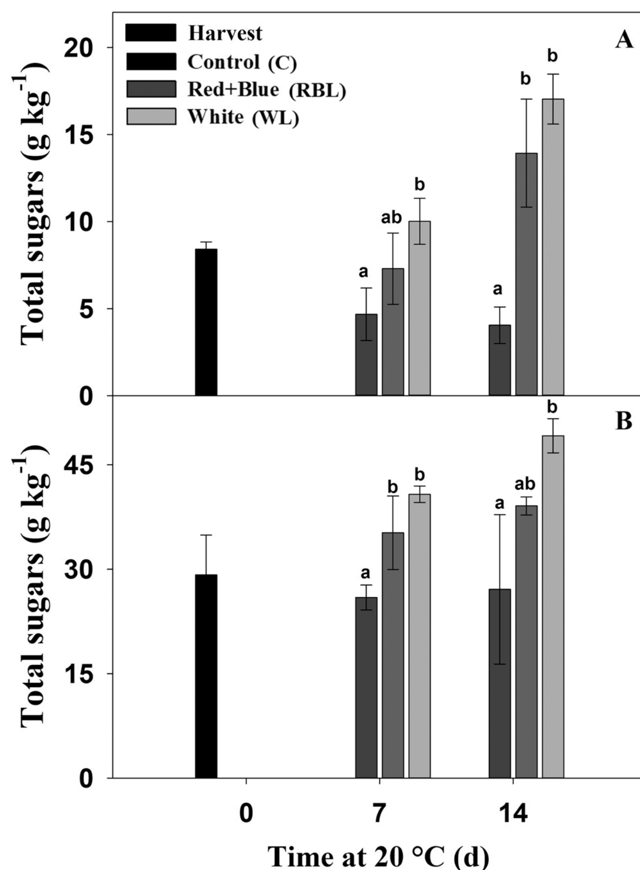


**Fig. 3.** Soluble sugars of alstroemeria leaves (**a**) and flower tepals (**b**) stored for 0, 7, or 14 d at 20 °C. Data represent means ± standard deviation. Different letters along a single storage day indicate significant differences based on the LSD test at a significance level of $P < 0.05$.

than the controls throughout storage (Fig. 3**B**). The flowers treated with RBL had a higher sugar content compared to the controls on day 7, but the differences observed on day 14 were not significant. On the other hand, the tepals of the controls stored in the dark had similar levels of soluble sugars from the beginning to the end of storage, albeit with a decreasing trend.

### *3.1.4. Hydrophilic and lipophilic antioxidants*

A higher content of hydrophilic antioxidants was observed in tepals than in leaves. In leaves, there was an increase in hydrophilic antioxidants in all floral stems, more evident in the controls towards day 14 (Table 1**A**). In tepals, no differences were observed during storage between the different treatments (Table 1**B**). Lipophilic antioxidants (carotenoids) in leaves increased only in the controls, while in flowers

**Table 1**

Hydrophilic (H-AOX) and lipophilic (L-AOX) antioxidants in leaves (A) or flower tepals (B), and anthocyanins in flower tepals of alstroemeria stored at 20 °C. Data represent means ± standard deviation (n = 3). Different letters within a column indicate significant differences based on the LSD test at a significance level of $P < 0.05$.

| A | H-AOX | | | L-AOX | | |
|---|---|---|---|---|---|---|
| | 0 | 7 | 14 | 0 | 7 | 14 |
| **Control** | 1.11 ± 0.0 | 1.28 ± 0.2 a | 1.73 ± 0.0 a | 128.4 ± 0.9 | 154.1 ± 3.8 a | 158.4 ± 4.0 a |
| **RBL** | 1.11 ± 0.0 | 1.18 ± 0.1 a | 1.45 ± 0.0 b | 128.4 ± 0.9 | 134.6 ± 2.8 b | 120.1 ± 3.8 c |
| **WL** | 1.11 ± 0.0 | 1.25 ± 0.0 a | 1.45 ± 0.1 b | 128.4 ± 0.9 | 127.5 ± 4.0 b | 131.2 ± 1.8 b |

| B | H-AOX | | | Anthocyanins | | |
|---|---|---|---|---|---|---|
| | 0 | 7 | 14 | 0 | 7 | 14 |
| **Control** | 1.55 ± 0.1 | 1.42 ± 0.1 a | 1.32 ± 0.0 a | 33.3 ± 1.0 | 37.2 ± 5.2 b | 37.65 ± b |
| **RBL** | 1.55 ± 0.1 | 1.31 ± 0.1 a | 1.35 ± 0.0 a | 33.3 ± 1.0 | 49.47 ± 13.5 ab | 36.38 ± b |
| **WL** | 1.55 ± 0.1 | 1.32 ± 0.1 a | 1.50 ± 0.1 a | 33.3 ± 1.0 | 66.92 ± 5.4 a | 60.07 ± a |

treated with WL and RBL, they remained at similar levels to the beginning of storage (Table 1**A**).

*3.1.5. Anthocyanins*

As the flowers matured during storage, the anthocyanin content in tepals increased and, to a greater extent, in flowers under WL and RBL (Table 1**B**). This increase was observed mainly at 7 d, after which the anthocyanin content generally decreased concomitantly with the advance of senescence. The flowers treated with WL showed the greatest anthocyanin content, followed by the RBL treatment. By 14 d of storage, while in RBL-treated flowers the anthocyanin content strongly decreased to levels similar to the controls, in WL-treated flowers there was only a slight decrease and tepals retained significantly higher anthocyanin levels than RBL and the controls.

## 3.2. Light treatment performed at 5 °C

*3.2.1. Water consumption and tepal area*

The accumulated water consumption in the flowers treated with WL was significantly higher than in the controls both at 26 and 36 d of storage (Fig. 4**A**). Water consumption did not have any influence on the stem diameter (data not shown). At 26 d the water consumption was higher than at 36 d for the WL-treated flower stems and the controls. During the flower development, from harvest to flower opening, the tepals grew and by day 26 of storage, both WL-treated and control flowers reached the maximum size, with no differences in size between 26 and 36 d of storage (Fig. 4**B**). At 26 d of storage, flowers treated with WL increased their tepal area by 25 % compared to the controls. At 36 d of storage, WL-treated flowers had tepals 12 % larger than the controls. Even at 36 d of storage, flowers treated with WL had larger tepals than the controls had on day 26.

*3.2.2. Leaf color and total chlorophylls*

During storage, there were important differences in leaf color between treatments (Fig. 5). An increase in leaf yellowing was observed in the controls, which had higher L* values, while in the WL flowers, no increase in L* was observed, remaining at values similar to the harvest (Fig. 5**B**). The green color, represented by the hue parameter obtained for the leaves, changed little in the WL-treated flower stems even at 36 d, while in the controls a constant decrease was observed during storage (Fig. 5**C**). Total chlorophylls decreased in all flower stems during storage at 5 °C. There was a delay in chlorophyll degradation in WL leaves, showing a substantially lower chlorophyll loss on all sampling days compared to the controls (Fig. 5**D**). While in WL-treated samples there were no differences between the last sampling days, flower stems stored in the dark showed faster chlorophyll degradation from harvest to 26 d and from 26 to 36 d. We measured 64 % and 170 % higher chlorophyll contents in WL-treated flower stems at 26 and 36 d of storage, respectively.

*3.2.3. Sugar content*

The total sugar content in leaves and tepals differed between treatments during storage. In the flowers treated with WL, a strong increase in sugar content was observed, mainly in leaves. In tepals, sugars increased up to 26 d in the WL flowers and remained without changes until day 36. In the controls, the sugar content almost did not vary during storage in leaves but decreased slightly in tepals. Compared to the controls, in WL flowers sugar contents were on average 5.3 and 2.6 times higher in leaves and tepals, respectively (Fig. 6).

*3.2.4. Hydrophilic and lipophilic antioxidants*

During storage, there was no significant increase in hydrophilic antioxidants in leaves from WL-treated flowers or controls. In tepals, higher hydrophilic antioxidants were observed from the beginning of storage, but there were no differences between treatments (Table 2**A, B**). In the case of lipophilic leaf antioxidants (total carotenoids in our study), no changes were observed in the WL-treated flower stems during storage, while an increase was noted in the controls at 26 and 36 d (Table 2**A**).

*3.2.5. Anthocyanins*

As floral maturity advanced during storage, an increase in

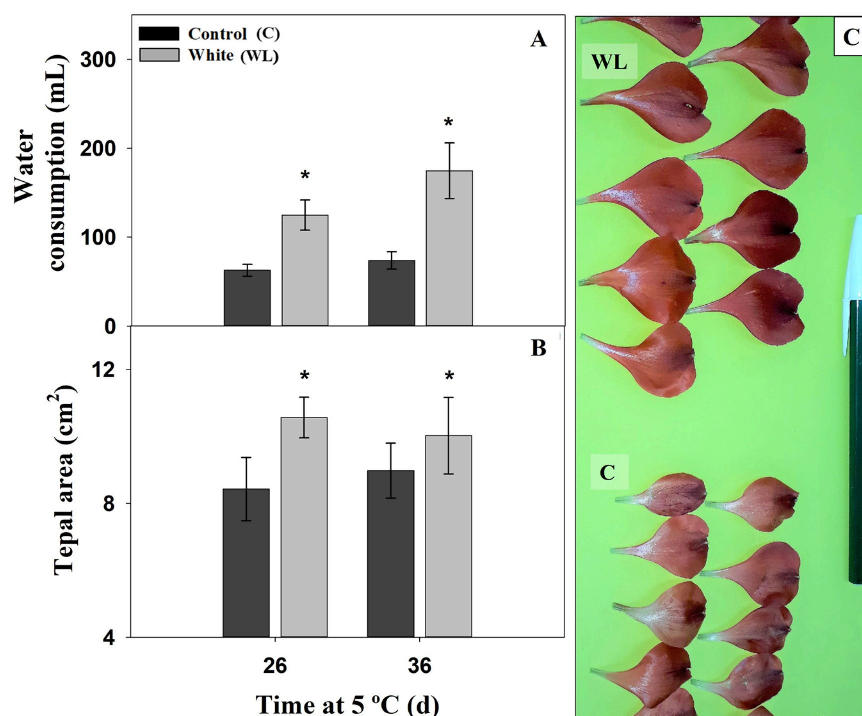


**Fig. 4.** Water consumption of floral stems (a), tepal area (b), and flower tepals of alstroemeria (c) at 26 d of storage at 5 °C. Data represent means ± standard deviation. Different letters along a single storage day indicate significant differences based on the LSD test at a significance level of $P < 0.05$.

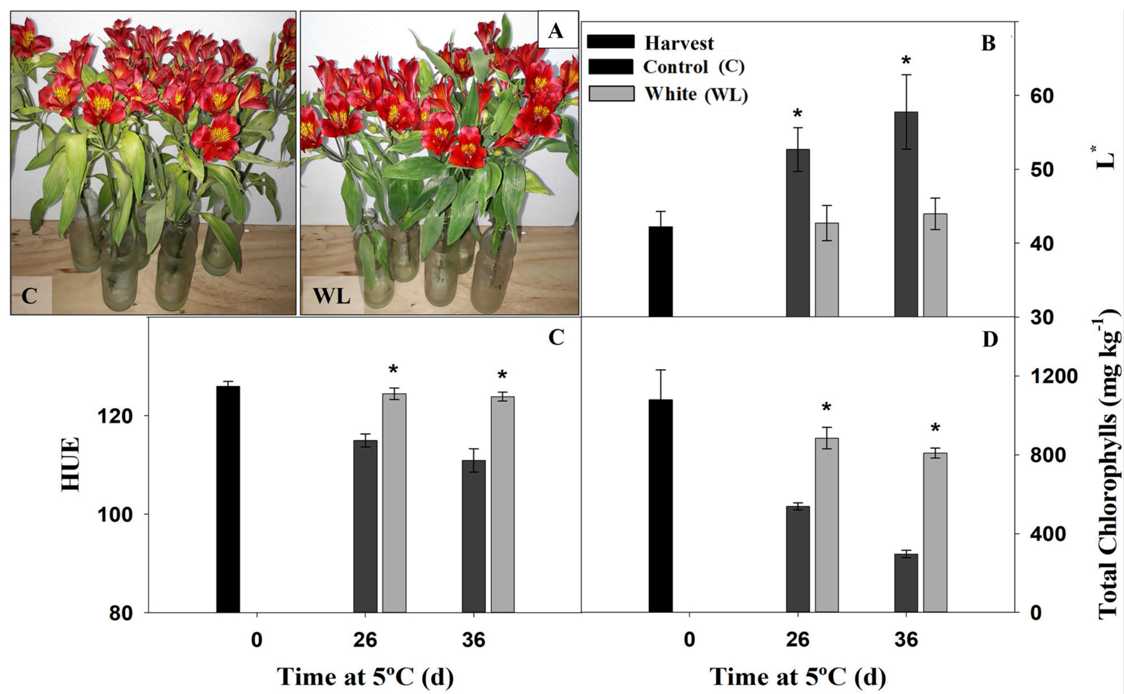


**Fig. 5.** Appearance of floral stems (**a**), color L* (**b**), hue (**c**) parameters, and total chlorophylls (a + b) (**d**) of alstroemeria leaves stored for 0, 26, or 36 d at 5 °C. Data represent means ± standard deviation. Different letters along a single storage day indicate significant differences based on the LSD test at a significance level of $P < 0.05$.

anthocyanin content was observed in all flowers, without significant differences between treatments on each sampling day (days 26 and 36) (Table 2**B**). However, considering all sample days combined, the WL-treated flowers had more anthocyanins than the controls. At 26 d, the flowers treated with WL had anthocyanin contents that the controls reached at 36 d.

## 4. Discussion

Alstroemeria cut flowers undergo accelerated leaf yellowing, which detracts from the quality of the floral stems even when tepal abscission has not begun. Consequently, the leaf color, the final flower size, and the time to abscission are the key aspects of alstroemeria quality at the time of marketing. Although refrigeration is an effective strategy to delay flower senescence and thus extend the marketing window, this is not always achievable in the marketing chain; besides, it is not a tool that improves the quality of the flowers, but only allows them to be kept for a longer time. The light conditions tested in the present work were effective not only for quality conservation but also for improving the floral stems, both at room temperature and under refrigeration. Compared to WL, the RBL treatment did not improve all the quality traits assessed, which can be associated with the spectral composition of both light sources, given that the applied intensities were similar. Light seems to exacerbate the enzymatic antioxidant system (Aalifar et al., 2020; Anvari et al., 2022), however, in the present work, we did not observe an increase in water-soluble antioxidants in alstroemeria, at least those that react with the Folin-Ciocalteu reactive.

It is unclear if an increase in the content of sugars in a tissue at a given time is a cause or a consequence of senescence and yellowing (van Doorn, 2008). Compared to controls, WL treatment significantly increased sugar content in leaves and tepals during storage at both 20 °C (3.4 and 1.8 times respectively) and 5 °C (6 and 2.9 times respectively). An increased carbohydrate supply to flowers, by starch hydrolysis or by synthesis, provides not only a substrate for respiratory processes but also osmolytes for water influx and cell expansion (van der Meulen-Muisers et al., 2001). The lighting with the RBL and WL sources may have increased stomatal conductance and with it produced the increase in water consumption observed, contributing to an increase in the size of the tepals.

Previous works showed that the photosynthetic rates of alstroemeria cut flowers seem to be very low (Jordi et al., 1994), and that starch is the dominant carbohydrate in alstroemeria tepals throughout the growth period (Collier, 1997). Many plants accumulate starch in the light and remobilize it during the dark period. Although starch degradation also occurs during the light period, this process is inhibited by trehalose 6-phosphate, a signal for sucrose availability. So, sucrose, a product of photosynthesis, can restrict starch degradation (Ishihara et al., 2022). In this work, we only measured soluble carbohydrates, found in greater amounts in light-treated flowers, so in these samples, we could also speculate about another carbohydrate source other than starch hydrolysis, such as photosynthesis.

Sugars could also play another role in the postharvest performance of flowers since it was observed that in alstroemeria and other species, there was a correlation between sugar content (at harvest or during storage) and postharvest longevity (van der Meulen-Muisers et al., 2001; Aalifar et al., 2020). van der Meulen-Muisers et al. (2001) found a relationship between the stage of bud maturity and the carbohydrate content in tepals, with mature buds containing more tepal carbohydrates. In WL and RBL-treated flowers, the ones with the highest carbohydrate content, we found in the sampling days a more advanced maturity stage, with larger tepals and higher anthocyanin content. Despite the observed maturity acceleration of flowers under WL, these flowers had the longest postharvest duration. The effect of light on the delay of chlorophyll degradation is well known in the literature, but the pathway by which light treatment delays chlorophyll degradation in leaves is still intriguing. Light not only provides an energy source for plants but also directs metabolism through photoreceptors such as phytochromes, which are sensitive mainly to the red band, one of the wavelengths that make up the WL source used in our experiments. Some phytochrome-interacting factors (PIFs) such as PIF4 and PIF5, belonging to a small family of transcription factors, have been indicated to be centrally critical in dark-induced senescence and chlorophyll

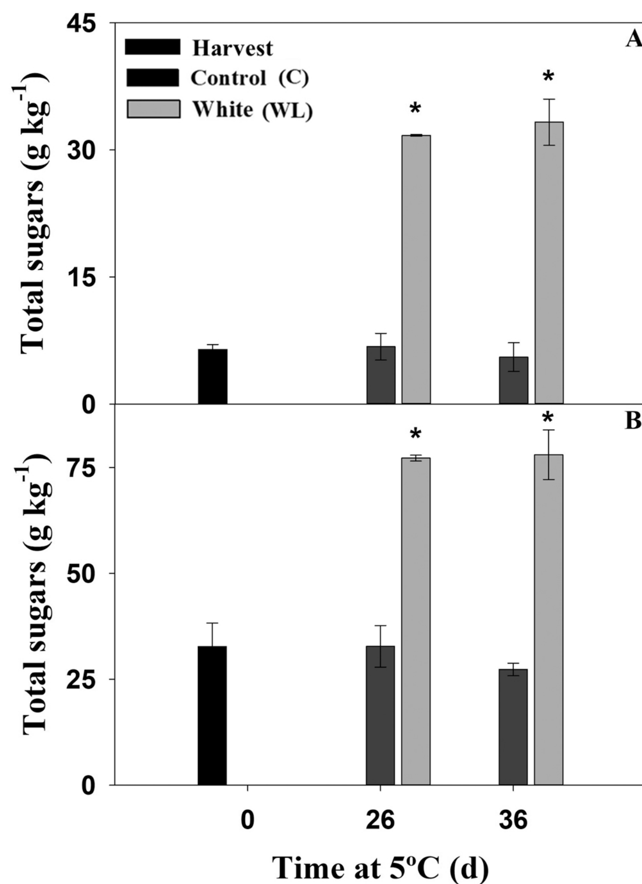


**Fig. 6.** Soluble sugars of alstroemeria leaves (**a**) and flower tepals (**b**) stored for 0, 26, or 36 d at 5 °C. Data represent means ± standard deviation. Different letters along a single storage day indicate significant differences based on the LSD test at a significance level of $P < 0.05$.

**Table 2**
Hydrophilic (H-AOX) and lipophilic (L-AOX) antioxidants in leaves (A) or flower tepals (B), and anthocyanins in flower tepals of alstroemeria stored at 5 °C. Data represent means ± standard deviation (n = 3). Different letters within a column indicate significant differences based on the LSD test at a significance level of $P < 0.05$.

| A | H-AOX | | | L-AOX | | |
|---|---|---|---|---|---|---|
| | 0 | 26 | 36 | 0 | 26 | 36 |
| **Control** | 1.11 ± 0.0 | 1.19 ± 0.0 a | 1.12 ± 0.0 a | 129.7 ± 2.9 | 152.3 ± 4.2 a | 157.1 ± 9.6 a |
| **WL** | 1.11 ± 0.0 | 1.13 ± 0.1 a | 1.38 ± 0.1 a | 129.8 ± 2.9 | 130.3 ± 4.4 b | 135.5 ± 1.8 b |
| **B** | **H-AOX** | | | **Anthocyanins** | | |
| | 0 | 26 | 36 | 0 | 26 | 36 |
| **Control** | 1.47 ± 0.1 | 1.54 ± 0.0 a | 1.50 ± 0.0 a | 12.16 ± 2.0 | 41.5 ± 6.5 a | 64.1 ± 8.9 a |
| **WL** | 1.47 ± 0.1 | 1.51 ± 0.1 a | 1.55 ± 0.1 a | 12.16 ± 2.0 | 64.2 ± 18.7 a | 81.9 ± 3.4 a |

degradation (Zhang et al., 2015). Apart from a higher proportion of the red band (and a small part of far red) in the WL source used for the treatment, the presence of other wavelengths, such as green, may influence the metabolism via photoreceptors other than phytochromes. Moreover, leaf senescence and yellowing can also be induced or suppressed by various phytohormones in diverse regulatory networks (Zhang and Zhou, 2013). Despite the complexity of the mechanisms involved in leaf yellowing, likely, the higher levels of sugars measured in the WL and RBL-treated flowers seem to have an important role in the metabolism of floral stems, delaying leaf yellowing and flower senescence, which ultimately affects alstroemeria postharvest quality and shelf life.

## 5. Conclusions

WL and RBL treatments at 20 °C and WL treatment at 5 °C maintained the quality and improved the appearance of alstroemeria floral stems during storage. The treatment with RBL improved the quality of the flowers compared to the controls stored in the dark, although not with all the analyzed quality parameters as it was observed for the WL treatment. The WL treatment not only maintained the harvest quality in terms of leaf greenness because of higher chlorophyll levels, but also improved other quality traits such as the turgidity and size of the tepals, as well as the anthocyanin content for at least seven days more than the controls stored in the dark (at 20 and 5 °C), and two days more than the RBL treatment (at 20 °C). The increase in soluble sugars observed in light-treated samples may have played an important role in the postharvest performance of alstroemeria flower stems. An illumination with WL from a LED source at an intensity of 50 μmol $m^{-2}$ $s^{-1}$ (≈ 11 W $m^{-2}$) at the top of the flower stem can be a clean suitable tool to delay the postharvest deterioration of alstroemeria leaves and flowers and even also improve the quality of floral stems mainly in two important moments in the marketing chain: at the grower (during storage after harvest) and at retail.

## CRediT authorship contribution statement

**Federico Pintos:** Formal analysis, Investigation. **Andrés Nico:** Writing – original draft, Writing – review & editing, Investigation. **Luis Rodoni:** Investigation. **Ramón Cieza:** Resources, Funding acquisition, Investigation. **Joaquín Hasperué:** Conceptualization, Formal analysis, Investigation, Writing – original draft, Supervision, Funding acquisition.

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## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data Availability

Data will be made available on request.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.postharvbio.2023.112346.

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