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Short light exposure preserves broccoli head quality and nutrients during refrigerated storage

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Abstract

This work explored a short light treatment performance to improve postharvest life and nutrients of broccoli heads stored at 5°C and 93% RH up to 22 days. A white LED was used as a light source. The intensity and exposure times were 9.5 W/m^2 and 3 hr per day. Compared to dark storage, the light treatment delayed color changes and preserved chlorophyll pigment levels. The weight loss, respiratory rate, and soluble proteins were not affected by light. After 13 days, the light-exposed broccoli had 40% more total sugars than those stored in the dark. At 13 and 22 days, the light-exposed broccoli had 40% and 70% higher ascorbic acid content, respectively, relating to dark-stored broccoli. Antioxidants and carotenoids in light-exposed broccoli were higher than in control. Three hours of white light per day exposure could be a useful technology to complement refrigerated storage of broccoli.

Practical applications

Refrigeration is the most effective and widespread technology to reduce vegetable senescence and post-harvest losses. Although, refrigerated broccoli loses its nutrients and quality very quickly. Complementary technologies to low-temperature storage become relevant for highly perishable products. The combined effect of light and refrigeration on broccoli heads has been assayed mainly by continuous light exposure during room temperature storage. Short light treatments are more practical, efficient, and convenient than continuous light exposure. A daily light exposure treatment (9.5 W/m^2 of white light for 3 hr) preserved broccoli heads' quality and nutrient contain under refrigeration. This non-chemical and safe treatment may complement the broccoli refrigeration during the storage and distribution chain.

1 | INTRODUCTION

Broccoli (*Brassica oleracea* var. *italica*) belongs to the *Brassicaceae* family. Broccoli immature inflorescence is a rich source of vitamins, phenolic antioxidants, glucosinolates, and fiber (Wang et al., 2017). Fresh broccoli is traditionally marketed whole from open bulk containers. Due to its high metabolic rate, the storage potential of broccoli is only 3–4 days at room temperature (Ma et al., 2014). Refrigeration extends the broccoli postharvest life, generally no more than 3 weeks at 5°C. Likewise, broccoli even loses its nutrients at a very high rate at refrigeration (Nath et al., 2011).

Various methodologies have been evaluated to preserves broccoli quality, including controlled (Li et al., 2016) and modified (Serrano et al., 2006) atmospheres, thermic treatment (Lemoine et al., 2010), ethanol vapor (Fukasawa et al., 2010), 1-MCP (Kumari et al., 2019), UV irradiation (Darré et al., 2017), and phytosulfokine α (Aghdam &

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Luo, 2021; Aghdam et al., 2020). These technologies provide benefits for broccoli, but these have difficulties related to its practicality and cost-benefit that have probably become an obstacle for their food-chain implementation. In recent years, interest has increased in the search for non-chemical and low-environmental impact strategies to improve vegetables postharvest performance (Romanazzi et al., 2016).

Light can delay senescence during postharvest (Jones, 2018). Continuous light exposure during storage at room temperature has delayed broccoli (Ma et al., 2014) and Brussels sprouts senescence (Hasperué, Rodoni, et al., 2016). Compared to continuous dark or continuous light, the short light exposure, so-called photoperiods, may even have higher benefits on delay green vegetable senescence (Favre et al., 2018; Jin et al., 2015; Liu et al., 2015). The combination of light and refrigeration has shown variable results, from good responses such as in intact and processed lettuce (Charles et al., 2018; Kasim & Kasim, 2017) or broccoli (Loi et al., 2019), until null effects (Olarte et al., 2009) or even deleterious in some commodities (Sanz et al., 2009; Xiao et al., 2014). The different response of each product to light, too long time exposure, or the use of suboptimal light intensities may explain these contradictory results.

Previously, we reported that short light exposure to white light preserved fresh-cut broccoli florets' quality during retail storage (Pintos et al., 2020). Moreover, some works examined a short light exposure in broccoli during room temperature storage (Bárcena et al., 2020). This approach may be valuable from a physiological point of view. Regarding broccoli heads, the combined effect of light and refrigeration has been studied mainly by continuous light exposure. Nevertheless, the effectiveness of short light exposure to maintain the quality of refrigerated broccoli heads needs to be determined. This strategy may be very relevant in transport and long storage conditions. Herein, we focused on a short-light treatment as a refrigeration complement for broccoli head preservation. In general, the LED light sources are energy efficient and generate relatively little heat (Morrow, 2008). But commercial-available LED still generates some heat, and their dissipation may become a problem under constant-lit storage. In terms of energy cost, implementation feasibility, and light source life, short-time light treatments could be more convenient and practical than constant light exposure for broccoli preservation. The objective of the present work was to evaluate the potentiality of short white LED light treatments (9.5 W/m^2, 3 hr d^{-1}) to preserve the postharvest quality and nutrient content of broccoli heads during refrigerated storage.

2 | MATERIALS AND METHODS

2.1 | Plant material

Broccoli (*Brassica oleracea* var. *Italica* cv. *Legacy*) was harvest at commercial maturity in a horticultural establishment of La Plata City (34° 59′39.1″ S; 58° 00′09.3″ W), Argentina, and immediately transported to the laboratory. Broccoli heads without defects were selected and washed with sodium hypochlorite (150 mg/L, pH 6.5) for 5 min.

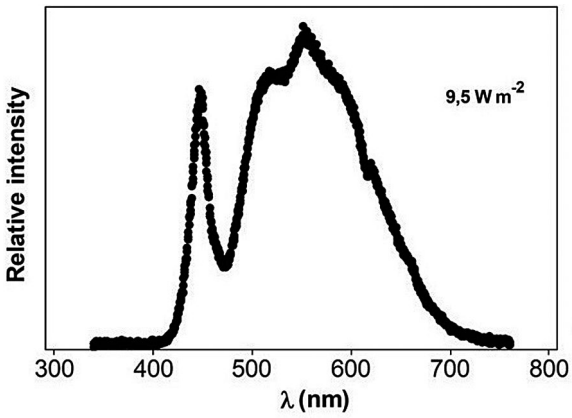

FIGURE 1 Light spectra used in this study

2.2 | Short light exposure and cold storage

The broccoli heads were placed in expanded polyester cups to evaluate the light effect, wrapped with perforated PVC, and stored at 5°C and 93% RH up to 22 days. The lighting device used was a 30 W plate composed of 66 LED bulbs (Triano, model: 10L069ISU7267, South American Lighting). A broccoli heads group received a single exposure of 3 hr to 9.5 W/m^2 cold white LED light (Figure 1) followed by a dark period each day. Based on previous results on minimally processed broccoli, the light intensity and time exposure were chosen (Pintos et al., 2020). To regulate the light intensity, the distance between broccoli heads and light sources was used (60 cm for 9.5 W/m^2). Another broccoli group was stored under the same conditions but under continuous dark. The film influence on the light transmission was checked. The PVC film effect on light transmission was null.

The broccoli heads were analyzed at 0, 13, and 22 days of storage. Ten broccoli heads per storage time and treatment were sampled. Samples were analyzed immediately or frozen in liquid N_2 and stored at −80°C until use.

2.3 | Color

The surface color of broccoli heads was determined by measuring the L^*, a^*, and b^* color components with a colorimeter covering a surface area of 8 mm^2 (Minolta CR400, Osaka, Japan). Ten broccoli heads for each treatment and storage time were analyzed. Three different positions of each broccoli head were measured and averaged.

2.4 | Weight loss and respiratory rate

The weight of broccoli heads before the storage, and after 13 and 22 days was registered. The percentage of weight loss, relating to the initial weight, was calculated. For the respiratory rate (RR), one broccoli head was placed in 5,000 ml bottles, sealed, and incubated in the dark at 5°C for 15 min. Through a septum placed in the bottle cap, a gas sample was withdrawn with a 1 ml syringe. The accumulated CO_2 into the flasks was determined using an infrared analyzer (Non-Dispersive Infrared Detector, Cavadevices, Argentina). Three broccoli heads were sampled for each treatment and storage time. The results were expressed as mg of CO_2 kg^{-1} hr^{-1}.

2.5 | Soluble protein content

Frozen flower buds were crushed in a laboratory mill and 0.5 g of the resultant powder was suspended and homogenized with 10 ml of buffer (50 mmol/L of Tris–HCl, 2 mmol/L of EDTA, 0.04 ml/100 ml of mercaptoethanol, pH 7.5). The mixture was centrifuged at 12,000 × *g* for 20 min at 4°C and the supernatant was used for soluble protein content determination according to Bradford (1976). Bovine serum albumin was used as a standard. Results were expressed as soluble protein mass in g per kg on a fresh weight basis. Three replicates were performed for each treatment and storage time. Each replicate corresponds to approximately 5 g of tissue obtained by sampling equal parts of 10 broccoli for each storage time and treatment and frozen in N_2 immediately.

2.6 | Chlorophylls and carotenoids

Frozen broccoli florets, sampled as described previously, were frozen in liquid N_2, crushed in a laboratory mill, and 0.4 g of the obtained powder was poured into 5 ml of acetone/water (80:20), stirred, and then centrifuged at 5,000 × *g* for 15 min. The supernatant was used to determine the Chlorophylls (Chl) and carotenoids content, according to Lemoine et al. (2010). Results were expressed in milligrams per kilogram on a fresh weight basis. Three extracts were performed per treatment and storage time.

2.7 | Sugars

Approximately 0.6 g of the frozen tissue powder, sampled as described previously, was homogenized with 5 ml of ethanol for 1 min in a vortex. The mixture was centrifuged at 5,000 × *g* for 10 min at 4°C; the supernatant was recovered and filtered through a 0.2 mm RC membrane (Cole-Parmer, USA). For the determination of sugar, high-performance liquid chromatography (HPLC, Waters 1525 Binary HPLC Pump) was used, equipped with a refractive index detector (Waters, IR 2414) and a Hypersil Gold Amino column (4.6 × 250 mm, 5 mm, Thermo Sci., USA). The samples were analyzed with an isocratic flow rate of 1.0 ml/min of acetonitrile/water (70:30) (Barreira et al., 2010). Individual sugars were calculated using external standards solutions prepared with analytical grade glucose, fructose, and sucrose in the range of 0.05–20 mg/ml. Sugar identification was performed on the basis of the retention time of the standard sugars samples. The sum of the three sugars analyzed represented the total sugars. Three extracts were performed per treatment and storage time. Measurements were performed in triplicate. Results were expressed as g/kg of sugar on a fresh weight basis.

2.8 | Ascorbic acid

Approximately 1 g frozen sample, obtained as described previously, was homogenized with 5 ml of 2.5% m/v metaphosphoric acid. The mixture was vortexed for 1 min and then centrifuged at 12,000 × *g* for 10 min at 4°C. The supernatant was recovered and filtered through a 0.2 mm RC membrane (Cole-Parmer, USA). The ascorbic acid (AsA) determination was performed using HPLC (Waters 1525 Binary HPLC Pump), equipped with a photodiode array detector, and a C18 column (4.6 × 150 mm, 5 mm, Waters Corp., USA) (Mazurek & Jamroz, 2015). The mobile phase was 0.5% m/v metaphosphoric acid/acetonitrile (93:7) at an isocratic flow rate of 1.0 ml/min. The detection was at 254 nm. For identification and quantification, a standard AsA solution was used. The results were expressed as mg of AsA per kg of fresh weight. Three replicates were made per treatment and storage time.

2.9 | Total phenols and total flavonoids

Ethanolic extracts were obtained from the frozen tissue powder sampled as described previously. A 50 µl volume of the extract was added to 950 µl of distilled water and 50 µl of Folin–Ciocalteu reagent diluted in water (1:1). After 3 min, 100 µl of a solution containing 20% (m/v) Na_2CO_3 in 0.1 mol/L of NaOH was added and brought to 2,500 µl with distilled water. The resulting solution was incubated at 25°C for 90 min (Singleton et al., 1999). The absorbance was measured at 760 nm. total phenols (TP) were expressed as g equivalent of chlorogenic acid per kg of fresh weight. Three independent extracts were analyzed per treatment and storage time.

Total flavonoids content was determined as Shin et al. (2007) with slight modifications. A volume of 30 ml of 5% $NaNO_2$ was added to 150 ml of ethanolic extract and 550 ml of distilled water was added. After 5 min at room temperature, 30 ml of 10% $AlCl_3$ was added. After 6 min, 80 ml of NaOH 1 M was added and the mixture was homogenized in a vortex. The absorbance at 510 nm was measured immediately. Quercetin was used as a standard. Measurements were performed in triplicate. Results were expressed as g per kg.

2.10 | TEAC

Measurements were performed according to Arnao et al. (2001). Ten microliters of a proper ethanolic extracts dilution were added to 1 ml

of ABTS·$^{+}$ working solution and vortexed. The absorbance at 734 nm was measured after 6 min. Trolox was used as standard and results were expressed as Trolox equivalents antioxidant capacity (TEAC, mg Kg^{-1}) on a fresh weight basis. The data presented are mean values of three statistical repetitions.

2.11 | Statistical analysis

The experiment was designed according to a 3 × 2 factorial design. Factors were storage time and light or dark storage. Data were analyzed with the ANOVA general linear model test using a Fisher's test using the software InfoStat (Di Rienzo et al., 2012) at a significance level of $p < .05$.

3 | RESULTS AND DISCUSSION

3.1 | Color and chlorophylls

The green color loss is the main factor limiting the postharvest life of broccoli (Li et al., 2017). The light treatment modified the color evolution in broccoli. The higher difference between treatments observed was after 22 days when the dark-stored broccoli luminosity (L^*) increased. In contrast, light-stored broccoli did not experience a significant change in L^* during all the storage (Figure 2a). There was no relevant difference between treatments in the a^* color component (Figure 2b). The b^* color component was higher in dark-stored than light-stored broccoli after 13 and 22 days (Figure 2c), indicating that broccoli turned yellow faster under dark. The short exposure to light delayed broccoli color deterioration during refrigerated storage. It is in line with other works where continuous or fractionally lighting delayed broccoli yellowing at room temperature (Favre et al., 2018; Jin et al., 2015; Ma et al., 2014). In contrast, white/red LED light failed to delay broccoli color change (Ma et al., 2014).

Before storage, the total broccoli Chl content was 21 mg/kg (Figure 3a). Chl followed the same pattern as the surface color. No changes in Chl were found after 13 days independently of light exposure. At the end of storage, light caused higher differences in Chl pigments. Broccoli Chl dropped 50% in the dark, while the light-exposed broccoli maintained their initial Chl levels. The ratio Chl a/b remaining unchanged during all the storage, independently of the light treatment (Figure 3a-c).Light exposure delayed green color degradation during room temperature storage of some leafy commodities (Liu et al., 2015) and broccoli (Favre et al., 2018). Light exposure can delay some Chl catabolism enzyme expression (Jiang et al., 2019). In broccoli, light exposure as a refrigeration complement has been approached mainly by continuous illumination. This strategy preserved broccoli (Hasperué, Guardianelli, et al., 2016) and lettuce (Kasim & Kasim, 2017) green color. It has been informed adverse effects in some products exposed to light for long periods. Continuous light treatment led to an increment in RR and metabolism, accelerating senescence (Olarte et al., 2009), and weight loss by transpiration

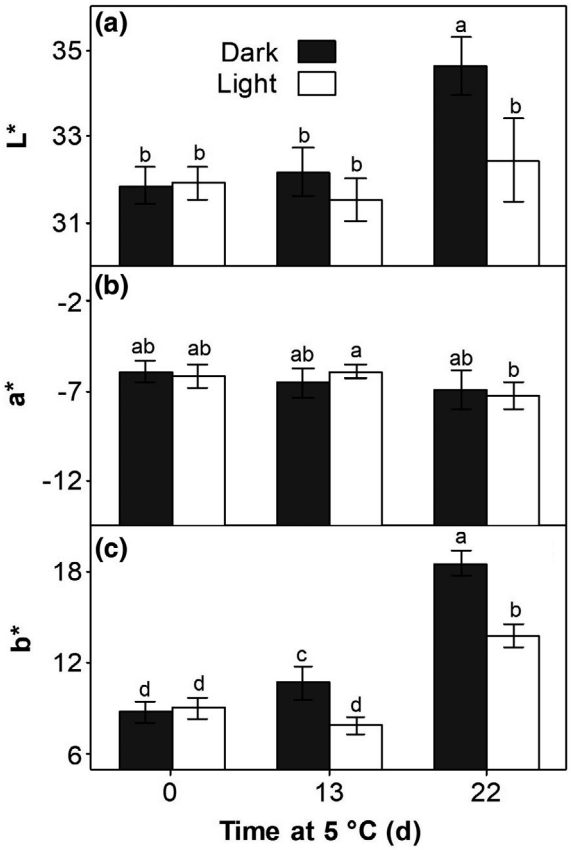

FIGURE 2 (a) Luminosity (L^*), (b) red–green color component (a^*), and (c) yellow–blue color component (b^*) of broccoli heads stored at 5°C for 0, 13, and 22 days in dark or exposed to 9.5 W/m^2 of white light 3 hr per day. Each column value and bar represent the mean and standard error, respectively. Different letters indicate significant differences between means based on a Fisher's test at a level of significance of $p < .05$

(Loi et al., 2019; Zhan et al., 2012). Short exposure to light could avoid such adverse effects.

3.2 | Weight loss, RR, and total soluble proteins

After the green color degradation, water loss is one of the main issues during broccoli storage, causing stalk hardening and bud clusters turgidity loss (Serrano et al., 2006). Broccoli exposed continuously to light may suffer high weight loss even at refrigeration (Loi et al., 2019). In this work, the weight loss was *c.a* 3 and 5.5% after 13 and 22 days, respectively, without differences between dark or light-exposed broccoli (Table 1). Broccoli sepals have stomata (Kunkel et al., 2020) and the higher weight loss observed in light-treated vegetables during the storage has been associated with the stomata opening (Noichinda et al., 2007). Although, the role of vegetables-stomata in the gas exchange with the surrounding atmosphere during postharvest-storage is not fully understood. Contrary to our results, at room temperature and using lower light intensity and time of exposure, Favre et al. (2018) reported higher

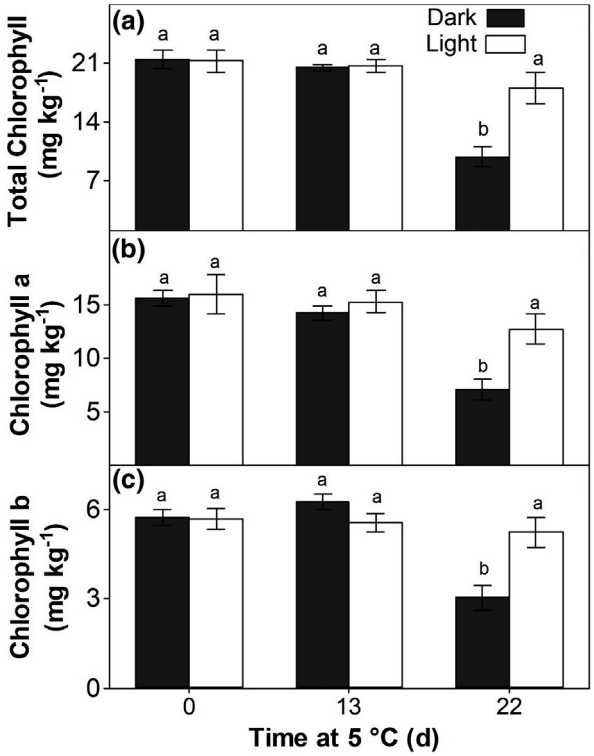

FIGURE 3 (a) Total chlorophylls, (b) chlorophyll a, and (c) chlorophyll b of broccoli heads stored at 5°C for 0, 13, and 22 days in dark or exposed to 9.5 W/m^2 of white light 3 hr per day. Each column value and bar represent the mean and standard error, respectively. Different letters indicate significant differences between means based on a Fisher's test at a level of significance of $p < .05$

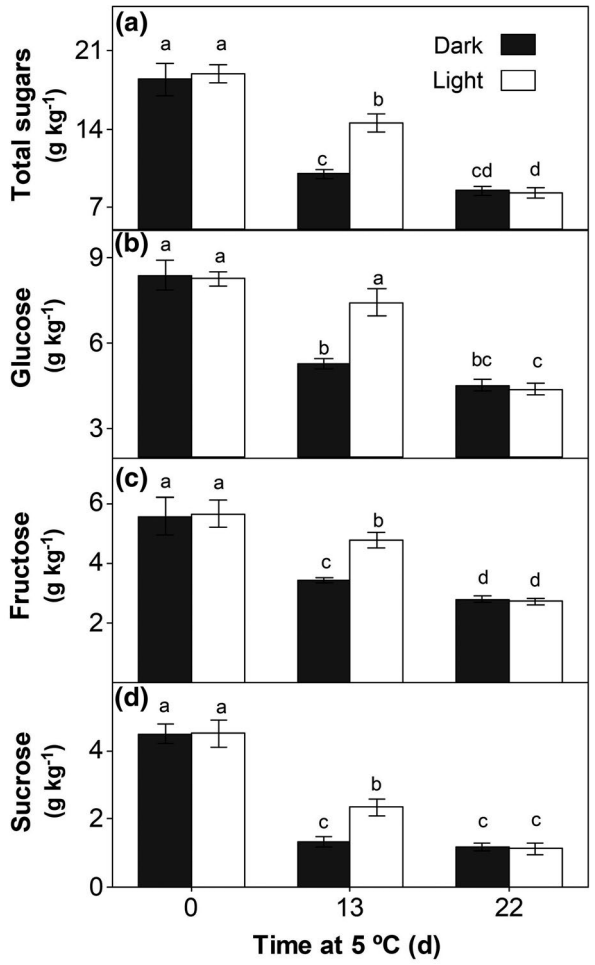

FIGURE 4 (a) Total sugars, (b) glucose, (c) fructose, and (d) sucrose of broccoli heads stored at 5°C for 0, 13, and 22 days in dark or exposed to 9.5 W/m^2 of white light 3 hr per day. Each column value and bar represent the mean and standard error, respectively. Different letters indicate significant differences between means based on a Fisher's test at a level of significance of $p < .05$

weight loss in light-stored broccoli than dark-stored. The temperature dependence of the vapor–pressure difference between the commodities and their surrounding atmosphere may explain this difference. In this study, broccoli heads were stored under refrigeration and exposed for a short period to light, a combination that likely avoided a high water vapor flux out the commodity. The results are in line with previous observations where short exposure to light of medium and high intensities reduced the weight loss of broccoli florets (Pintos et al., 2020).

The broccolis RR was 32–35 mg CO_2 kg^{-1} hr^{-1} during the first 13 days (Table 1). At the end of storage, the RR was reduced, without further differences between treatments. This RR pattern toward the end of storage in refrigerated broccoli has been observed previously, without correlation with the product deterioration degree (Lemoine et al., 2010). As for water loss, light can increase the RR of vegetables by a similar stomata mechanism (Ayala et al., 2009; Olarte et al., 2009). Other authors had related the increment in RR with the etioplast differentiation into chloroplasts stimulated by light (Wulfkuehler et al., 2014). In this study, there were no significant changes in the RR derived from short light exposure. Soluble proteins showed a decreasing trend during storage (Table 1). Soluble proteins are respiratory substrates and that their content decrease during postharvest storage may be expected (Lemoine et al., 2010). Although, the soluble proteins of dark or light-exposed broccolis showed no differences. Daily treatment with 9.5 W/m^2 white light for 3 hr preserved the broccoli color without increasing weight loss, RR or soluble protein consumption.

3.3 | Sugars

In the beginning, the total sugars and the levels of glucose, fructose, and sucrose were *c.a.* 18, 8.0, 5.5, and 4.5 g/kg, respectively (Figure 4). After 13 d in the darkness, total sugars decreased 42%, in agreement with previous reports that showed a significant sugar decrease during broccoli storage compared to other nutrients (Hasperué et al., 2011). In the light-exposed broccolis, only 17% of the total sugars decreased in the same period. The higher sugar decrease observed was in sucrose probably due to the high broccoli invertase enzyme activity (Eason et al., 2007). After 13 days, the

TABLE 1 Weight loss, respiratory rate, and total soluble proteins of broccoli heads stored at 5°C for 0 (when corresponding), 13, and 22 days in dark or exposed to 9.5 W/m^2 of white light 3 hr per day

	Weight loss (%)		Respiratory rate (mg CO_2 kg^{-1} hr^{-1})		Total soluble proteins (g kg^{-1})	
Time at 5°C (d)	Dark	Light	Dark	Light	Dark	Light
0	–	–	32.0 ± 1.0a	31.5 ± 0.2a	5.3 ± 0.2a	5.2 ± 0.1a
13	3.4 ± 0.6b	2.9 ± 0.4b	31.6 ± 0.9a	34.6 ± 1.3a	3.8 ± 0.1b	3.9 ± 0.2b
22	5.7 ± 0.8a	5.2 ± 0.5a	20.5 ± 2.8b	24.4 ± 3.3b	3.1 ± 0.1c	3.1 ± 0.1c

Note: Mean ± *standard deviation* are shown. Different letters indicate significant differences between means based on a Fisher's test at a level of significance of $p < .05$.

light-treated broccoli had higher levels of sucrose than dark-stored heads. The glucose and fructose contents remained almost constant after 13 days in light-treated broccoli, while in dark-stored broccoli, a reduction of 40% in both sugars was observed. Similarly, light exposure delayed sugar loss in kale (Noichinda et al., 2007), celery (Zhan et al., 2014a), and refrigerated spinach (Toledo et al., 2003). At the end of storage, both treatments showed lower sugar levels without differences between them (Figure 4b-d). Some works have negatively correlated the broccoli senescence rate with soluble sugar levels (Jani & Mankad, 2013). Here, the reduction in sugar levels in dark-stored broccolis seems to precede the senescence symptoms (Figures 2–4). In light-exposed broccoli, the higher sugar levels found could be related to a lower RR and carbon demand (Hasperué et al., 2011). Interestingly, light caused no differences in the broccoli respiratory rate (Table 1). Some authors have also suggested a residual photosynthetic activity in green vegetables during low-temperature postharvest storage (Charles et al., 2018; Noichinda et al., 2007; Toledo et al., 2003). In any case, the short exposure to light (3 hr) and the low-temperature storage seem to suggest that some other mechanisms beyond photosynthesis are involved in the maintenance of sugar levels observed herein. The light can induce sugar movement from one shaded side of the vegetal to another side exposed to light (Magwaza et al., 2013). We analyzed the sugar content in the flower buds. A sugar translocation from the stalk to flower buds may have been possible, and this could partly counterbalance buds' sugar loss. Further studies are necessary to understand how light conserves higher broccoli sugar levels better.

3.4 | Antioxidants

Broccoli is considered a rich vegetable due to its high antioxidants and glucosinolates content (Wang et al., 2017). We analyzed the levels of AsA, carotenoids, TP, total flavonoids, and TEAC since these nutrients can vary considerably during storage (Lemoine et al., 2010; Rybarczyk-Plonska et al., 2014). The AsA content before storage was 850 g/kg. The AsA decreased in both treatments with a faster AsA decrease in broccoli stored in darkness. After 13 days, the AsA content in light-stored broccoli was 70% of their initial value, whereas dark-stored conserved only 40% (Figure 5a). The difference in AsA was still significant after 22 days. The light treatment highly delayed the AsA loss. There are different light effects on broccoli ASA levels during storage reported in the literature. In broccoli, the light induced AsA synthesis genes (Ma et al., 2014). In broccoli florets, light preserved AsA during storage (Pintos et al., 2020). In other studies, a 12 hr light photoperiod (Rybarczyk-Plonska et al., 2014) or continuous white/blue light (Hasperué, Guardianelli, et al., 2016) caused a null effect in AsA comparing with dark storage. The highest AsA level found here may indicate the vegetal redox status maintenance (Das & Roychoudhury, 2014). It is consistent with the lowest senescence observed in terms of color and Chl.

There was no variation in the carotenoid content of dark-stored broccoli thought storage. In contrast, the carotenoid of light-stored broccoli incremented 50% at the last sampling date (Figure 5b). Light is known to be an effector inducing carotenoid biosynthesis. Carotenoids quench $^1O_2$ under light, protecting the photosynthetic reaction center against photooxidation (Wulfkuehler et al., 2014). In outer leaves of Brussels sprouts (Hasperué, Rodoni, et al., 2016) and refrigerated kale leaves (Noichinda et al., 2007), has also been reported carotenoid accumulation under constant light exposure. This carotenoid accumulation may improve broccoli's nutritional quality.

The TP were around 3 g/kg at the beginning. After 13 days under both light and dark storage, a TP reduction was observed. After 22 days, a TP increment was found. The total flavonoids showed a decreasing trend during all the storage (Figure 6a,b). Both the TP levels and total flavonoids were higher in light stored broccoli compared with those under darkness during all the storage. In contrast, Jin et al. (2015) observed a TP accumulation in dark-stored broccoli at 25°C but, in line with the found herein, was found higher phenol levels in broccoli stored under white-fluorescent and green LED treatments. Zhan et al. (2014b) reported a positive correlation between phenylalanine ammonium lyase enzyme activity and light.

In dark-stored broccoli, the TEAC remained stable during all the storage (Figure 6c). Since the TP levels showed a decreased trend, the constant TEAC observed may suggest the de novo polyphenols synthesis with higher antioxidant power against the ABTS$^{\cdot+}$ radical. At the end of the storage, in light-stored broccoli, the TEAC increased (Figure 6a) despite the reduction in AsA observed (Figure 5a). These results suggest that, in broccoli, the TP contribution to the overall antioxidant capacity measured by the ABTS$^{\cdot+}$ radical would be higher than the AsA contribution. A similar pattern was found previously (Hasperué, Guardianelli, et al., 2016). The higher antioxidant capacity may reduce the ROS generated during storage resulting in lower broccoli senescence.

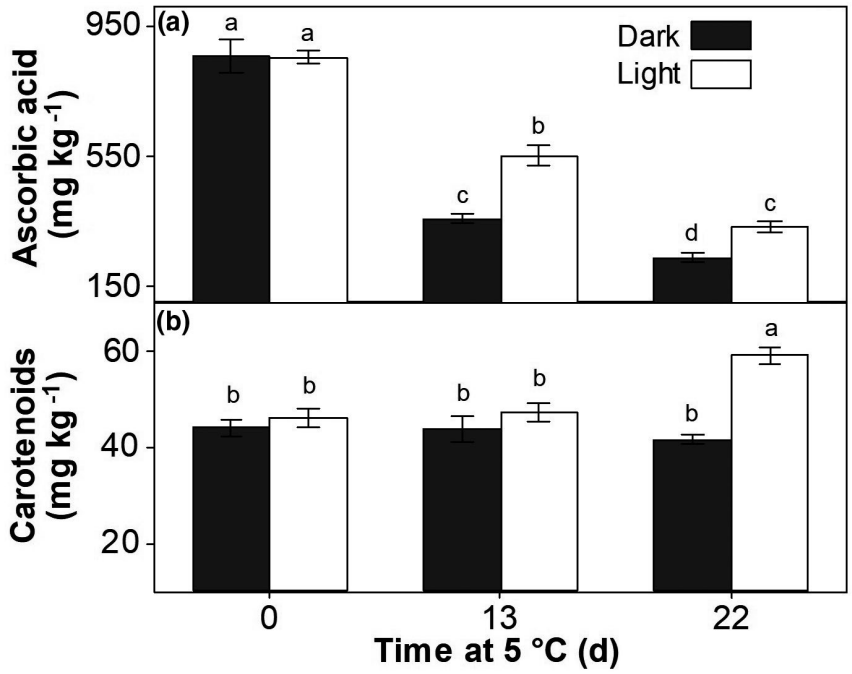

FIGURE 5 (a) Ascorbic acid and (b) carotenoids of broccoli heads stored at 5°C for 0, 13, and 22 days in dark or exposed to 9.5 W/m^2 of white light 3 hr per day. Each column value and bar represent the mean and standard error, respectively. Different letters indicate significant differences between means based on a Fisher test at a level of significance of $p < .05$

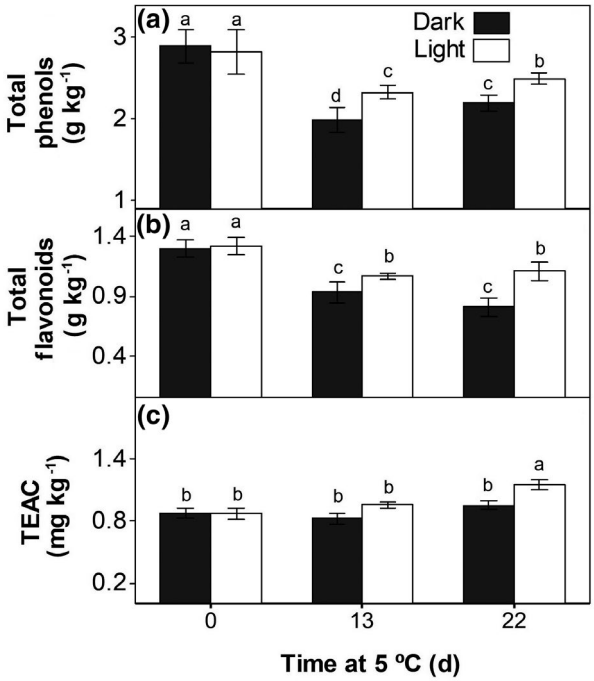

FIGURE 6 (a) Total phenols, (b) total flavonoids, and (c) TEAC of broccoli heads stored at 5°C for 0, 13, and 22 days in dark or exposed to 9.5 W/m^2 of white light 3 hr per day. Each column value and bar represent the mean and standard error, respectively. Different letters indicate significant differences between means based on a Fisher's test at a level of significance of $p < .05$

4 | CONCLUSIONS

A white light treatment, with 9.5 W/m^2 of 3 hr per day, was evaluated as a refrigeration complement. Compared with dark storage, light exposure successfully delayed yellowing, preserving color, and Chl without adverse effects in weight loss, RR or soluble proteins. After short storage times, light markedly modulated the sugar levels. Short light exposure preserved broccoli nutritional properties maintaining higher AsA, TP, and total flavonoids levels relating to broccoli stored in the dark. Also, light caused carotenoids and TEAC increments at the end of the storage. Short light exposure could be a useful, safe, and low-cost technique to complement the broccoli heads refrigeration during the storage and distribution chain.

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CONFLICTS OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTIONS

Federico M. Pintos: Data curation; Formal analysis; Investigation; Writing-original draft. **Joaquín H. Hasperué:** Investigation; Project administration; Resources; Visualization. **Pablo Ixtaina:** Resources. **Ariel R. Vicente:** Resources; Supervision; Writing-original draft. **M. Laura Lemoine:** Investigation; Methodology; Visualization; Writing-original draft. **Luis M. Rodoni:** Formal analysis; Methodology; Supervision; Writing-original draft; Writing-review & editing.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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