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Use of LED light for Brussels sprouts postharvest conservation

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ABSTRACT

Yellowing is the most evident symptom of senescence in green vegetables during postharvest storage. As chlorophyll synthesis is promoted by blue light, illumination would be a clean alternative to maintain healthier vegetables for longer. In this paper was assessed the effect of white-blue light-emitting diodes (WB LED) on outer and inner leaves (OL, IL) of Brussels sprouts during 10 d storage at 22 °C. The treated sprouts showed lower respiration rate and remained greener with a better visual quality, with more than 10 times chlorophylls than controls in OL and 1.6 times in IL towards the end of the storage period. The OL had a higher content of antioxidants (DPPH• and $ABTS^{\bullet+}$ assays) than the IL, and the treatment increased the AOX only in the OL. Total flavonoids content was higher in OL than IL, and about 20% higher in treated samples at day 10 of storage. The storage of Brussels sprouts under continuous low intensity WB LED was effective in delaying the senescence. The effect of the treatment was visible not only in the leaves exposed to light (OL) but also in the IL. The WB LED lighting would be useful to maintain or improve the quality of Brussels sprouts for both storage and transport.

1. Introduction

One of the major postharvest problems of green vegetables is the yellowing of the tissues due to senescence, which leads to a loss of nutritional and commercial value. As other cruciferous, Brussels sprouts (*Brassica oleracea* var *gemmifera*) has been studied for its nutritional value (Viña et al., 2007a) and for the benefits against some diseases, included cancer (Fujioka et al., 2016; Liu et al., 2013). Yellowing of tissues is caused by chlorophyll degradation during tissue senescence. After the harvest, the outer leaves of Brussels sprouts suffer yellowing and dehydration, making the product to loose market value or diminish the yield, since the producers remove the outer yellowed leaves to continue selling the product. Some efforts have been made to delay postharvest yellowing in Brussels sprouts, such as heat treatment (Wang, 1998), edible coating (Viña et al., 2007b) or fluorescent lighting (Kasim and Kasim, 2007) with different results. Brussels sprouts are a group of imbricated leaves, and for its nature, it is possible to use low-disturbing methods with light to maintain the photosynthetic system active, extending the green color and enlarging the shelf life of sprouts. While conventional lighting could have an adverse effect by raising the temperature in the storage room, the use of narrowed light would avoid using wavelengths not useful for the photosynthesis as infrared band, wasting less energy when considering a postharvest continuous or photoperiodic exposure to light. It is known that the influence of blue light on the development of the photosynthetic apparatus as well as its relationship with chlorophyll biosynthesis (Fan et al., 2013; Terfa et al., 2013; Wang et al., 2015). Other studies have observed a delay in senescence by using blue LED light instead of white and red LED, due to an extension in the duration of active photosynthesis (Wang et al., 2015), and an increment of the photosynthetic capacity, increasing stomatal conductance and chlorophyll content (Hogewoning et al., 2010). Although the LED light has been used to a greater extent in vegetable seedlings (Li et al., 2010; Wu et al., 2007), studies in postharvest storage are also promissory (Hasperué et al., 2016; Jin et al., 2015).

Given the lack of background in the use of narrowed light sources in Brussels sprouts postharvest conservation, the aim of this work was to assess the effect of the continuous white and

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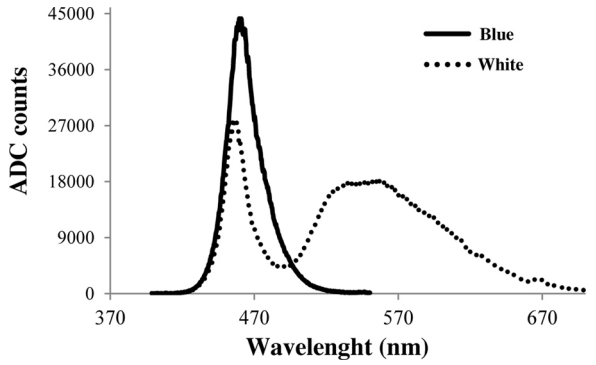

Fig 1. Spectral composition of blue and white LEDs used during the experiment.

blue LED exposition on quality of Brussels sprouts (inner and outer sprout leaves) stored at 22 °C.

2. Materials and methods

2.1. Plant material and light treatment

Brussels sprouts (*Brassica oleracea* var. *gemmifera*) grown under conventional agricultural practices were harvested in a farm in La Plata, Argentina (34° 59′S and 58° 3′W) at 8:00 a.m. from plants of an age of approximately eight months. Harvested sprouts were transported within an hour to the laboratory. Sprouts were selected by their size and the first whorl of small leaves was discarded to uniform their quality. The sprouts were placed in plastics trays, wrapped with perforated PVC to avoid excessive dehydration and stored at 68% humidity at 22 °C under continuous white and blue LED light (WB LED) SMD 3020 model. Controls were stored in dark at the same humidity and temperature. The light intensity was selected according to previous researches (Büchert et al., 2011) maintaining a photosynthetic photon flux (PPF) level to 20 μmol m^{-2} s^{-1}, measured with a PAR meter (Radlogger RAD1, Cavadevices, Argentina). The treatment was carried out by disposing white and blue LED strips at a distance of 9 cm from the sprouts, in order to achieve the desired dose of photons. The emission spectrum was measured with a spectrometer (AvaSpec-ULS3648-USB2-UA-25, Avantes) and the peak of blue and white LED was 458–467 nm and 450/525-558 respectively (Fig. 1).

Samples were taken after 0, 5, or 10 days and evaluated for color, respiration rate and weight loss or frozen in liquid nitrogen and stored at −80 °C for further analysis. Before freezing and to compare the effect of the treatment on the metabolism of different leaves of the sprout, the outer two whorls of leaves (OL), those exposed to daylight in the field, were separated from inner leaves (IL), the ones covered completely for the outer leaves. The whole experiment was repeated twice, in consecutive years.

2.2. Weight loss and respiration rate

For the weight loss determination, the entire sprouts were weighed during the sampling days mentioned above and weight loss (WL) was calculated from initial (IW) and final weights (FW) as:

$$WL\ (\%) = \frac{(IW - FW)}{IW} x\ 100$$

For respiration measurement, approximately 300 g of whole Brussels sprouts were placed inside 3 l flasks, closed hermetically and incubated for 10 min at 20 °C. The CO_2 concentration was determined using an infrared analyzer (CompuFlow Model 8650, Alnor, USA) and results were expressed as rate of CO_2 evolution in μg kg^{-1} s^{-1}. Four measurements were done for each treatment and storage day.

2.3. Surface color

The color evaluation was performed with a colorimeter (Minolta CR-400, Osaka, Japan) using the Hunter L*a*b* scale: L* varies from 0 (black) to 100 (white), a* positive values are red and negative values are green, and b* positive values are yellow and negative values, blue. The hue angle (h°) was calculated as $h^o = \tan^{-1}\left(b/a\right)$ when a and $b > 0$ or $h^o = 180^o + \tan^{-1}\left(b/a\right)$ when $a < 0$ and $b > 0$.

All measurements were made in the two outer leaves that wrap the sprout.

2.4. Chlorophylls and carotenoids

The OL and IL stored at −80 °C were ground separately with a grinder and the procedure was performed according to Hasperué et al. (2016). Chlorophylls and total carotenoids were determined with a spectrophotometer (U-1900, Hitachi Corp., Tokyo, Japan) according to Lichtenthaler (1987) and expressed as mg kg^{-1} in a fresh weight basis. All measurements were done by quadruplicate.

2.5. Total soluble sugars (TSS)

IL and OL were frozen with liquid nitrogen and ground in a grinder. Approximately 0.6 g of the obtained powder were homogenized in 5 ml ethanol, vortexed and centrifuged at 5500 × g for 8 min at 4 °C. Four extracts per sample and storage time were obtained. The supernatants were recovered and utilized to determine the content of TSS by the anthrone method. Briefly, one milliliter of 2 g l^{-1} anthrone prepared H_2SO_4 (98% w/w) was added to 10 μl ethanolic extract, mixed and held at 100 °C in a water bath for 10 min. The test tubes were cooled in water for 20 min and the absorbance at 620 nm was measured in a spectrophotometer. For quantification, a standard glucose solution was employed and results were expressed on a fresh weight basis as g kg^{-1}.

Table 1
Weight loss (WL%) and respiration rate (RR) values of treated and control samples during postharvest storage at 22 °C. Data are presented as mean (n = 4) ± standard error.

	WL (%)		RR (μg CO_2 kg^{-1} s^{-1})	
	C	WB LED	C	WB LED
0 d	0.00 ± 0.00	0.00 ± 0.00	31.29 ± 1.42 b	31.29 ± 1.42 b
5 d	3.19 ± 0.14 a	7.19 ± 0.17 b	35.69 ± 4.42 b	22.46 ± 1.46 a
10 d	6.45 ± 0.07 b	15.04 ± 0.82 c	32.60 ± 2.20 b	24.41 ± 2.72 a

Different letters indicate, in each parameter, differences at $P < 0.05$ among treatments and storage days (Duncanís test).

Table 2
Changes in Hue (°) and lightness (L*) values of treated and control samples during postharvest storage at 22 °C. Data are presented as mean (n = 35) ± standard error.

	Hue (°)		Lightness (L*)	
	C	WB LED	C	WB LED
0 d	119.4 ± 0.29 d	119.4 ± 0.29 d	58.5 ± 0.68 a	58.5 ± 0.68 a
5 d	104.4 ± 1.05 b	118.8 ± 0.3 d	76.74 ± 1.04 c	61.51 ± 0.71 b
10 d	96.2 ± 0.49 a	115.7 ± 0.91 c	77.64 ± 0.54 c	62.56 ± 1.04 b

Different letters indicate, in each parameter, differences at $P < 0.05$ among treatments and storage days (Duncanís test).