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Effect of light on quality and bioactive compounds in postharvest broccoli florets

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ABSTRACT

The effect of light treatment (fluorescent and light-emitting diode (LED) green light) on shelf life, visual quality and bioactive compounds in broccoli florets was investigated. The results showed that light treatment extended shelf life and inhibited the decrease of *H* value and chlorophyll contents in broccoli florets stored at 25 °C. The content of total phenols and glucosinolates were markedly increased by LED green light, but no effect on sulforaphane. Fluorescent and LED green light treatment significantly increased DPPH radical scavenging activity in broccoli, but little effect was found between the two light treatments. These results indicated that LED green light could be a useful technique for extending shelf life, maintaining visual quality and preventing decrease of bioactive compounds in broccoli florets.

1. Introduction

Broccoli (*Brassica oleracea* L. ssp. *italica*) is a very popular vegetable due to its green colour and high value of nutrients. It has been suggested that broccoli is rich in protein, vitamins, phenolics, glucosinolates and sulforaphane, which are much higher than other green vegetables (Martínez-Villaluenga, Frías, Gulewicz, Gulewicz, & Vidal-Valverde, 2008). Yellowing of green vegetables during storage is normally considered to be the major consequences of chlorophyll degradation. The green colour of broccoli is an important commercial quality, which reflects the deterioration progress in the florets. The main problem in broccoli stored at ambient temperature is rapid senescence and yellowing, which reduces it commercial quality (Jia et al., 2009). Various storage techniques have been widely investigated to extend shelf life and improve visual or nutritional quality in broccoli, such as the use of modified atmospheres package, 1-methylcyclopropene (1-MCP), UV-C irradiation, 6-benzylaminopurine treatment and so on (Costa, Vicente, Civello, Chaves, & Martinez, 2006; Xu, Yang et al., 2012; Yuan, Sun, Yuan, & Wang, 2010). Cooling, refrigeration and transportation with ice are effective techniques to maintain visual quality of broccoli, however, cold storage or cold chain facilities are not usually available in developing countries. Broccoli florets are always handing, storage or transportation at ambient temperature after harvest in China (Yuan et al., 2010). Thus, it is necessary to find new techniques to extend the shelf life of broccoli at ambient storage temperature.

Light is one of the most important environmental factors affecting the phytochemical content in plant tissue (Massa, Kim, Wheeler, & Mitchell, 2008). Fluorescent and metal halide lamps are widely used supplemental lighting for greenhouses. It had been found that light exposure was effective on shelf-life and visual quality in lettuce, radish microgreens and spinach (Samuoliene, Sirtautas, Brazaityte, & Duchovskis, 2012; Toledo, Ueda, Imahori, & Ayaki, 2003; Xiao et al., 2014). As to broccoli florets, postharvest yellowing and senescence were also delayed by low intensity light treatment (Zhan, Hu, Li, & Pang, 2012). Light-emitting diode (LED) lighting sources are ideal for use in plant lighting system due to its small size, durability and relatively cool emitting surfaces (Bourget, 2008). Many studies show that LED light is more suitable for plant growth than that of a fluorescent lamp (Li, Xu, & Tang, 2010). Recently, several scientists have stated that postharvest LED treatment could enhance antioxidant capacity in some vegetables including lettuce, barley leaf, spinach and komatsuna (Ohashi-Kaneko, Takase, Kon, Fujiwara, & Kurata, 2007; Samuoliene et al., 2012). However, little information is available on the effect of LED light treatment on visual and nutritional quality in broccoli florets. The objective of this study was to investigate the effect of fluorescent and LED green light treatment on shelf life, visual quality, antioxidant capacity and health-promoting compounds during storage at ambient temperature.

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2. Materials and methods

2.1. Plant material and treatment

Broccoli (*B. oleracea* L. var. *italica* cv. Chaoda No. 1) heads were hand-harvested from a local commercial farm in Nanjing, China. The heads of broccoli were placed on ice and carried back to the laboratory within 4 h of harvest. Broccoli heads were selected for uniform size, colour and absence of mechanical damage, and then randomly divided into three groups of 30 head each and subjected to following treatments: (1) Control: Broccoli heads were stored in dark condition (light intensity about 0.1 $\mu mol\ s^{-1}\ m^{-2}$); (2) Fluorescent: Broccoli heads were stored were stored under continues fluorescent light (FL40D-EX/38, Huadian, China) at broad wavelengths of 400–700 nm (light intensity about 12–13 $\mu mol\ s^{-1}\ m^{-2}$); (3) Green light: Broccoli heads were stored were stored under continues light-emitting diode (LED) green light (Blue LED mode-3150, Philips Electronics, Netherlands) at wavelengths of 520 nm (light intensity about 12–13 $\mu mol\ s^{-1}\ m^{-2}$). Fluorescent and LED green light was applied within 12 h per day, and the other 12 h was in dark condition. The light intensity was measured by an OPT-2000 spectral photometer (Optpeco, Beijing, China). All the broccoli heads were stored at 25 ± 1 °C (ambient temperature) and about 95% relative humidity for 2 days. Each treatment was replicated three times, and the experiment was conducted twice. Samples were taken daily, and florets were removed from the stems. Then the florets were immediately frozen in liquid nitrogen and kept at −80 °C for later analysis.

2.2. Analysis of shelf life, colour and chlorophyll content

Shelf life was evaluated according to the method by Ku and Wills (1999). The time for quality to decline to 30% yellowing in broccoli florets was assigned as their shelf life. Florets colour was determined on intact heads of broccoli using a Minolta Chromameter (CR 400, Japan). Throughout the experiment, colour readings were evaluated at five positions on each head daily. L^* was lightness (0–100: 0 = black, 100 = white). The H value (hue angle) was calculated as $H = \tan^{-1}(b/a)$ when $a > 0$ and $b > 0$ or $h^\circ = 180^\circ + \tan^{-1}(b/a)$ when $a < 0$ and $b > 0$. Chlorophyll content was determined according to the method by Yuan et al. (2010). Chlorophyll quantification was measured at 665 and 649 nm and the result was expressed as milligrams of chlorophyll mass per gram of fresh weight.

2.3. Determination of DPPH radical-scavenging activity, total phenol, sulforaphane and total glucosinolate content

DPPH radical scavenging activity of broccoli florets was determined according to the method by Hatano, Kagawa, Yasuhara, and Okuda (1988). The absorbance was measured at 550 nm, and result was calculated according to the following formula: DPPH radical scavenging activity (%) = 100 − (absorbance of sample/absorbance of control) × 100.

The total phenolics content was determined with the Folin–Ciocalteu reagent according to the method by Slinkard and Singleton (1977) measuring the absorbance at 765 nm. Results were expressed as milligram of gallic acid equivalent per gram fresh weight.

Sulforaphane was extracted from broccoli samples according to the method by Liang, Yuan, Dong, and Liu (2006). Two gram of broccoli floret was grinded with 2 mL 0.5 U mL^{-1} myrosinase (25 UN, Sigma) solutions. After recovery of the liquid, the residue was dissolved in 1 mL acetonitrile and was passed through a 0.45 μm membrane filter. 20 μL of extracted sample was injected and analysed by high-performance liquid chromatography (HPLC) system (1100, Agilent Corp., Santa Clara, CA). Samples were separated at 30 °C on a Kromasil C18 column (250 × 4.6 mm) using acetonitrile and water at a flow rate of 1.0 mL min^{-1}. Sulforaphane (Sigma, St Louis, MO, USA) was used as an external standard for HPLC analysis. Absorbance was measured at 254 nm and the results were expressed as microgram of sulforaphane per gram fresh weight.

Total glucosinolate content was measured by using the method of Heaney, Spinks, and Fenwick (1988). The content of glucose was determined by the method of phenol–sulphuric acid, to assay the absorbance at 490 nm, and then the amount of glucosinolate can be calculated from the glucose content.

2.4. Statistical analysis

All statistical analyses were performed with SPPS Version 14.0 (SPSS Inc., Chicago, IL, USA). Data were analysed by two factors, light treatments and storage time, analysis of variance (ANOVA). The main effects and the interactions were analysed and the means were compared by Duncan's multiple range tests at a significance level of 0.05.

3. Results

3.1. Effect of light on shelf life in broccoli florets

Broccoli deteriorates rapidly as florets turn yellow, and has very short shelf life at ambient temperature. As shown in Fig. 1, treatment with fluorescent and green light significantly ($P < 0.05$) prolong shelf life of broccoli after harvest. The shelf life of broccoli florets treated with LED green light extended to almost three times than that of control florets.

3.2. Effect of light on surface colour and chlorophyll content in broccoli florets

Changes of surface colour during broccoli yellowing were evaluated through the hue angle (H°) and L^* parameters. L^* value increased and H° value decreased in broccoli during storage. LED green light treatment significantly inhibited the increase of L^* value, however, no significant ($P < 0.05$) difference was found between fluorescent treatment and control. Both fluorescent and

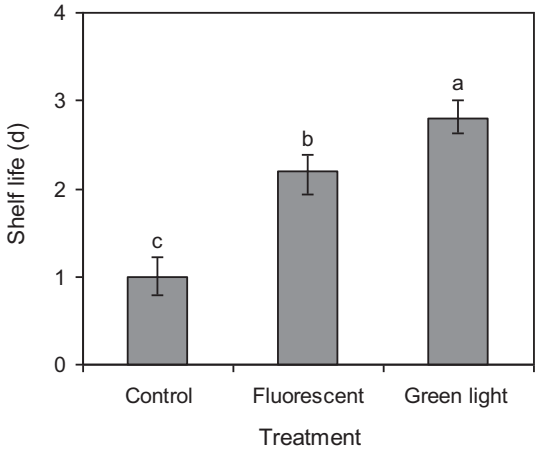

Fig. 1. Effect of light treatment on shelf life of broccoli florets stored at 25 °C. Values are the means ± SE of triplicate assays. Vertical bars represent the standard errors of the means. Data in columns with the different letters are significantly different $P < 0.05$.