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Short period irradiation of single blue wavelength light extends the storage period of mature green tomatoes

Radhika Dhakal, Kwang-Hyun Baek*

School of Biotechnology and LED-IT Fusion Technology Research Center, Yeungnam University, Gyeongsan, Gyeongbuk 712-749, Republic of Korea

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ABSTRACT

Major postharvest quality factors of mature green tomatoes were investigated to improve their long-term storage. Mature green tomatoes pretreated with blue light (440–450 nm) emitted from blue light emitting diodes (LEDs) for 7 days developed a yellowish color and high levels of firmness, while those pretreated with darkness or red light (650–660 nm) from red LEDs for the same period ripened and developed red color. The pretreated tomatoes were incubated in darkness at room temperature, and a^* and b^* values, firmness and lycopene contents were measured after 7, 14, and 21 days of storage. The tomatoes pretreated with blue light had delayed softening; however, these tomatoes ripened fully, recovering red color development and accumulation of lycopene during 21 days of storage in darkness. These findings indicate that simple single blue wavelength illumination can be an effective application to extend the shelf-life of tomatoes by delaying fruit softening and ripening. Further studies should be conducted to characterize the roles and regulatory mechanisms of the components involved in the delay of tomato ripening by blue light.

1. Introduction

The high levels of lycopene and antioxidants in tomato make it an economically important and popular fruit in terms of human health (Madhavi and Salunkhe, 1998). Tomatoes are rich in fibers, vitamins A and C, and lycopene, and therefore an excellent source of dietary antioxidants and anticancer agents (Franceschi et al., 1994; Giovannucci, 2002; Giovannucci et al., 2002; Lenucci et al., 2006). The most important quality criteria for the distribution and marketing of tomatoes are their color, firmness, flavor, freedom from decay and postharvest durability and safety (Garrett et al., 1960; Grierson and Kader, 1986).

Many studies have been conducted to extend the postharvest shelf-lives of fruit and vegetables (Vicente et al., 2005; Costa et al., 2006; Biswas et al., 2012). The causes of postharvest loss in vegetables and fruit can be categorized as physiological, pathological, physical and combinations of these three factors (Holt et al., 1983). Tomato ripening is an orchestrated process that results in major physiological and metabolic changes, eventually leading to fruit decay and seed dispersal (Pirrello et al., 2009). It is evident that ethylene production, chlorophyll degradation, lycopene synthesis and cell wall softening are the main ripening-related factors in tomatoes (Fischer and Bennett, 1991; Giovannoni, 2004). Therefore, postharvest loss of tomatoes from early ripening can be reduced by applying pre-conditioning treatments and storage conditions that help to control the factors that initiate ripening. Ripening-inhibiting methods include the supply of gibberellins, kinetin, ascorbic acid and exposure of green tomatoes to temperatures above 30 °C (Khudairi and Arboleda, 1971; Tijskens and Evelo, 1994).

Irradiation with UV light has been shown to extend freshness during storage and improve nutrients and quality of vegetables and fruit (Liu et al., 2009; Kim et al., 2011). For instance, UV light delays chlorophyll degradation, reduces tissue damage and disruption, and maintains antioxidant capacity, ultimately extending the storage period of broccoli (Costa et al., 2006). UV-A irradiated tomatoes showed normal color development and ripening without any physiological disorder (Maneerat et al., 2003), and similarly, UV-C light delayed the development of tomato tissue color and softening (Maharaj et al., 1999). Although UV-light influences the postharvest physiology of tomatoes, to the best of our knowledge, there have been no reports of the effects of blue light wavelengths on the postharvest physiology of mature green tomatoes. The recent rapid development of light emitting diodes (LED) has made it possible to illuminate plants or their products with a narrow range wavelength. Because of this, the simple application of LED has been very successful in identifying the roles that specific wavelengths play in plant development and physiology (Noda and Fujita, 2009; Hogewoning et al., 2010).

The present study was carried out to investigate preservation of the postharvest quality of mature green tomatoes by applying light at a single wavelength and then storing the tomatoes in darkness.

* Corresponding author. Tel.: +82 53 810 3029; fax: +82 53 810 4769.
E-mail address: khbaek@ynu.ac.kr (K.-H. Baek).

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Mature green tomatoes were selected for this study because they can ripen even after being detached from the vines, and are the appropriate stage for commercial purposes, as well as for extending postharvest life (Chomchalow et al., 2002). Important quality factors were recorded in mature green tomatoes after illumination with blue light (440–450 nm wavelengths from blue LEDs) or red light (650–660 nm wavelength from red LEDs) for 7 days as a pretreatment to postharvest storage in darkness for 21 days.

2. Materials and methods

2.1. Tomatoes, treatment and storage

Mature green tomatoes (*Solanum lycopersicum* L. cv. Dotaerang) of similar size (150–200 g) were obtained from a local farmer from June to August, 2012 after cultivation in a plastic house under natural sunlight. All experiments were repeated three times; however, the data presented here were selected from a single experiment. The tomatoes were kept in separate sectors in a chamber at 25 ± 2 °C under continuous irradiation by either blue light or red light at 85.72 μ Einstein m^{-2} s^{-1} and 102.70 μ Einstein m^{-2} s^{-1} for 7 days, respectively. Another group of tomatoes were kept in a different sector of the same chamber without any light supply. After 7 days of treatment, all treated tomatoes were subsequently transferred to darkness at 25 ± 2 °C and a relative humidity of 60–65% for 7, 14 or 21 days (short-, middle-, or long-term storage, respectively), after which changes in quality factors were investigated.

2.2. Surface color measurement

Surface color measurement was conducted using a color measurement device (Minolta CR-300, Minolta, Japan) to analyze four equatorial parts of each tomato. The color parameters L^*, a^* and b^* were measured after 7, 14 and 21 days of storage. L^* represents lightness and ranges from black (0) to white (100), a^* ranges from green (−) to red (+), and b^* ranges from blue (−) to yellow (+).

2.3. Lycopene contents and total soluble solids (TSS)

The contents of lycopene were determined according to the method described by Javanmardi and Kubota (2006), with some modification. A total of 0.5 g of tomato pericarp was cut and homogenized with 45 mL of extraction solution (hexane, ethanol and 0.05% butylated hydroxytoluene in acetone at a 1:1:1 ratio). The extracted solution was then shaken on ice for 20 min at 180 rpm in a shaking incubator, after which 6 mL of ice cold distilled water was added and the samples were shaken for another 10 min in the incubator. The samples were then removed from the shaker and allowed to stand at room temperature for 20 min to allow the polar and non-polar compounds to separate. Next, the supernatant containing the hexane layer was separated and filtered using a 0.45 μm millipore filter (Sartorius Stedim Biotech, Goettingen, Germany). The absorbance at 503 nm was then measured using a microplate reader (Infinite M200, Tecan, Mannedorf, Switzerland) to calculate the content of lycopene. The costar EIA/RIA, 96 well half area, flat bottom plate was used. The lycopene content was calculated using the formula described by Javanmardi and Kubota (2006):

$$\text{Lycopene}\ \ (\text{mg kg}^{-1}\ \text{FW}) = \left(\frac{x}{y}\right) \times A503 \times 3.12$$

where x is the amount of hexane (mL) and y is the weight of fruit tissues (g). It should be noted that the values are expressed in g kg^{-1} in the present study.

The sap from squeezed tomato pericarps was analyzed for TSS using a refractometer (PAL-1 Pocket Refractometer, Atago, Japan). The TSS expressed in percentage (%) represents the TSS concentration in tomatoes as grams of solids per 100 mL (Giovanelli et al., 1999).

2.4. Firmness

The force required to penetrate the tomatoes was measured in two locations on each tomato using a pocket penetrometer (Model FHR-5, Nippon Optical Works Co. Ltd. Japan). The firmness in newtons (N) was measured at 7, 14 and 21 days of storage.

2.5. Statistical analysis

All numerical data represent the means of three samples ± the standard deviation (SD). The variance of the sample data was identified by Duncan's test using the statistical analysis software (SAS) version 9.1 (SAS Inc., Cary, NC, USA). All experiments were replicated three times.

3. Results

3.1. Surface color

After 7 days, tomatoes treated with darkness and red light turned red, while those treated with blue light were yellowish (Fig. 1). Within 7 days of subsequent transfer to darkness at room temperature, the yellowish tomatoes previously treated with blue light also turned red, but showed less red color development than those that were previously treated with darkness (Fig. 1). Visual inspection verified less red color development in tomatoes treated with blue light after 14 days of storage in darkness, but no difference was observed among groups after 21 days of storage in darkness (Fig. 1).

Further quantitative analysis of color was conducted using the colorimetric method. On days 7 and 14 of storage in darkness, the a^* values were positive in all treated groups, although those of tomatoes pretreated with blue light were significantly lower than those of tomatoes pretreated with darkness or red light (Fig. 2A). After 21 days of storage, there was no significant difference in the a^* values of tomatoes subjected to different pretreatments (Fig. 2A).

The yellowish tomatoes pretreated with blue light for 7 days showed red color development following subsequent storage in darkness for 7 days. In contrast to the pattern of a^* values, the b^* values of tomatoes pretreated with blue light were significantly higher than those pretreated with darkness or red light after 7 or 14 days of storage in darkness, but did not differ significantly after 21 days of storage (Fig. 2B).

The L^* values of tomatoes pretreated with darkness were significantly lower than those of tomatoes pretreated with blue light after the first 7 days of storage in darkness. After 14 days of storage in darkness, the L^* values from all samples decreased and did not differ significantly among groups (Fig. 2C).

3.2. Firmness

There was a gradual decrease in the firmness of all tomatoes as the storage time increased (Fig. 3). Tomatoes pretreated with blue light maintained significantly higher levels of firmness than those pretreated with darkness over 21 days of storage in darkness, with decreases in firmness of 20.0% and 34.0%, respectively, occurring during the storage period. After 21 days of storage in darkness, the firmness of tomatoes pretreated with blue light was highest among all groups (Fig. 3).