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Effect of UV-C on ripening of tomato fruits in response to wound

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ABSTRACT

Tomato fruits were dropped from 1.5 m to simulate wound, treated with 4.1 kJ/m^2 ultraviolet-C (UV-C) radiation, stored at 20 °C for 12 d. During storage, firmness, color, ethylene production, respiration rate, lycopene, chlorophyll, protopectin, water soluble pectin (WSP), pectin methyl esterase (PME) and polygalacturonase (PG) activities of the tomato fruits were analyzed. UV-C delayed the decrease of firmness and hue angle in wounded tomato fruits. Lycopene accumulation and chlorophyll degradation were retarded by UV-C. Wound advanced the climacteric ethylene production and respiration rate peaks, while a delay up to 4 d in UV-C treated fruits was found. UV-C significantly postponed protopectin degradation and WSP accumulation, which were associated with the delay of PME and PG activities and contributed to the firmness maintenance. These results indicated that UV-C could maintain quality and delay wounded tomato fruits ripening.

1. Introduction

Fresh fruits are very susceptible to wound during harvesting, packaging, handling and transport, which can lead to higher risk of bacterial and fungal contamination, as well as lower shelf-life and result in a substantial reduction in quality (Li and Thomas, 2014; Zeebroeck et al., 2007). Previous studies have reported the physical and biochemical characteristics of postharvest fruits in response to wounds (Pérez-Vicente et al., 2002). Wound could stimulate ethylene and CO_2 production of mature-green tomato fruits, leading to fast ripening process and reduced shelf life (Macleod et al., 1976). In order to make the postharvest fruit more widely marketed, some methods have been used to alleviate the wound, such as polyamines treatment (Pérez-Vicente et al., 2002; Valero et al., 1998), chitosan coating (Li et al., 2012), forced-air cooling (Martínez-Romero et al., 2003), calcium and heat treatments (Serrano et al., 2004). With the extensive use of mechanical equipment for harvesting, packing, and transporting, the development of techniques to alleviate wound is in urgent demand for horticultural products.

One of the environmentally friendly practices considered to extend shelf-life and preserve quality in horticultural products is UV-C. Treatment of fruits and vegetables with UV-C, has been shown to have a number of benefits. These include enhanced nutritional value of the fruits (Charles et al., 2016), slowed rate of maturation (Severo et al., 2015), and delayed senescence (Obande et al., 2011). Barka (2001) described increased activity of antioxidant enzymes in tomatoes exposed to UV-C. Jiang et al. (2010) also reported an increased antioxidant enzymes activity in shiitake mushrooms treated with UV-C after harvest. Rodoni et al. (2012) found that UV-C was useful to maintain refrigerated fresh-cut green pepper quality. Moreover, UV-C treatment can enhance the antioxidants, reduce microbial count and extend the shelf life of fresh-cut Chokanan mango and Josephine pineapple (George et al., 2015). Additionally, Choi et al. (2015) reported that the UV-C application on fresh-cut paprika could extend its shelf life. These results suggest that UV-C is feasible treatments for shelf-life extension of fresh-cut fruits and vegetables. Postharvest UV-C treatment has the potential to become a technological alternative to improve wounded fruits and vegetables conservation.

A postharvest research of UV-C radiation in wounded tomato fruits has not been found. The objective of this study was to verify the physical and metabolic changes induced by UV-C in tomato fruit after wound.

2. Materials and methods

2.1. Fruit and treatments

Tomato fruits (*Solanum lycopersicum* L. cv Zheza 205) were gotten from a local fruit packinghouse on the harvest day and transported to our laboratory in Hangzhou, China. To get uniform color

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fruits, all fruits were stored at 20 °C for 24 h and selected visually by surface color when they had got the mature-green stage of ripeness. Fruits that free of visual defects and uniform in size were selected. Fruits were separated into four groups (90 × 4) and each group was separated into three lots. The first sample fruits (Control) were directly stored at 20 °C. The second sample fruits (Wound) were dropped from 1.5 m to the concrete floor. In order to avoid the generation of bruising of fruit, spongy pads were placed around the point of impact. Tomato fruit with visible wound and epidermis fracturing were removed. The area of the fruit that directly impacted the floor was marked with a black line. The height of 1.5 m was selected from 0.5, 1.0, 1.5, 2.0, 2.5 m according to our per-experiments as to stimulate wound. The third sample fruits (UV-C) were treated by 4.1 kJ/m^2 UV-C radiation (This UV-C dose was chosen as being optimal from preliminary experiments). Irradiation intensity was measured by a portable digital radiometer. The fourth sample fruits (Wound+UV-C) were dropped from 1.5 m to the concrete floor one by one, and then treated by 4.1 kJ/m^2 UV-C radiation. Tomato fruits were placed on plastic trays and stored at 20 °C for 12 d. Firmness, peel color, respiration and ethylene production were assessed every 3 d. Fruit mesocarp samples taken from the direct impacted area (about 50 g each) were frozen in liquid nitrogen and stored at −20 °C for further analysis.

2.2. Firmness assessment

Firmness assessment were performed with a texture analyzer (TA-XT2i, Stable Micro Systems Ltd; Godalmin, UK) incorporating a 5 mm diameter probe. Nine fruits from each group were compressed 5 mm at a rate of 0.5 mm s^{-1} on the equatorial damaged area and the maximum force was documented and described in Newton (N).

2.3. Peel color

Peel color of all each of the nine fruits on equatorial wounded area in each group was determined with a Minolta Chroma Meter CR-410 (Minolta Camera Co., Osaka, Japan).The a*, b* and Hue° (Hue angle, H° = arc tangent (b*/a*), green = 180°, yellow = 90°, red = 0°) were quantified (McGuire 1992).

2.4. Ethylene evolution and respiration

Three 1 L airtight chambers were used to evaluate the ethylene production. Three fruits from each group per chamber were enclosed for 1 h at 20 °C, then, 1 mL gas sample was collected using a syringe. Each sample was injected into a gas chromatograph (SP 6800-A; Lunan Chemical Engineering Instrument Ltd; Tengzhou, Shandong Province, PR China). And the results was described as μL h^{-1} kg^{-1}. Three replicates were conducted in each treatment.

Respiration was determined as the rate of CO_2 production. Nine fruits (three fruits per chamber) from each group were sealed in a chamber and air was passed through the chamber. The effluent air was joined to a GXH-3051 (Institute of Junfang Scientific Instrument; Beijing, China) Infrared Gas Analyser (IRGA) and the respiration rates expressed as mg h^{-1} kg^{-1}. Three replicates were conducted in each group.

2.5. Lycopene content determination

The determination of total lycopene content was carried out by using the method described by Sadler et al. (1990) with some modifications. 5 g of tissue were homogenized with a tissue homogenizer in 50 mL hexane/ethanol/acetone (2:1:1 v/v/v). Cold distilled water (15 mL) was added and the suspension was agitated for 10 s. The solution was set for 15 min and the up layer solution was removed and evaluated the absorbance at 503 nm using a spectrophotometer. Lycopene calculations were made using an extinction coefficient of 17.2 L mol^{-1} m^{-1} (Zechmeister et al., 1943) and expressed as mg kg^{-1}.

2.6. Chlorophyll measurement

Chlorophyll was evaluated by the method of Knee (1972). Frozen fruit peel (approx. 5 g) was ground and extracted with 50 mL cold acetone, containing 1% calcium carbonate to avoid degradation. The residue was washed with cold acetone until the residue became colorless. The extracts were combined, adjusted to 100 mL with acetone, and centrifuged at 14,000 × g for 10 min at 4 °C. Chlorophyll content was analyzed from the absorbance of the supernatant at 645 nm and 663 nm as follows: $7.12 \times (A_{663}) + 16.8 \times (A_{645})$. Chlorophyll was described as mg kg^{-1}.

2.7. Pectin extraction and analysis

Frozen fruit flesh (20 g) was extracted in 100 mL boiling 95% ethanol for 30 min, then cooling to room temperature. The tissue was further homogenized for 5 min and vacuum-filtered through a glass fiber filter. The residue was washed twice with 20 mL ethanol and 20 mL acetone, respectively. The alcohol-insoluble solids (AIS) were dried in an oven (40 °C).

AIS (1.0 g) were detached in 100 mL distilled water, shaken overnight at 20 °C and vacuum-filtered. The residue was suspended in 100 mL distilled water, shaken for 1 h and filtered again. The filtrates were collected and were used for WSP determination. The precipitate was hydrolysed in H_2SO_4 (0.5 M) at 100 °C for 1 h and used for protopectin analyzation. WSP and protopectin were measured according to the method of Bu et al. (2013) and described as g kg^{-1}.

2.8. Enzyme extraction and activity assay

Frozen flesh (10 g) were ground in two volumes of cold sodium acetate buffer (100 mM, pH 6.0) containing polyvinyl pyrrolidone (10 g kg^{-1}, PVP, MW 44,000), and centrifuged at 14,000 × g for 20 min. The residue was suspended in two volumes of sodium acetate buffer (1 M, pH 6.0) containing NaCl (60 g kg^{-1}). The pH of the suspension was attuned to 8.2 with NaOH (2 M). The sample was preserved overnight at 4 °C with continuous stirring and then centrifuged. The supernatant was filtered twice and the filtrate was dialyzed against distilled water for 48 h with four changes. All operations were performed in an ice bath. This dialyzed sample was used as enzyme extract for assaying PG and PME.

PME activity was measured as described by Nagel and Patterson (1967). The substrate used was a solution of pectin (10 g kg^{-1}). The pH of the pectin solution was attuned to 7.0 with 0.02 M NaOH. The reaction mixture contained 10 mL of the crude enzyme, 5 mL sodium oxalate (0.2 M) and 25 mL substrate. The reaction mixture was incubated at 30 °C and continuously stirred by bubbling CO_2-free air through it. The pH of the reaction mixture was maintained at 7.0 with NaOH (0.02 M) during the reaction. The amount of 0.02 M NaOH added was recorded over 30 min. The activity of PME is described in units per kilogram of tomato tissue (U/kg). One unit of PME activity was defined as milliequivalents of ester hydrolysed per second.

PG activity was evaluated by the methods of Gross (1982). Reaction mixture comprised 10 mLcrude enzyme and 10 mL polygalacturonic acid (10 g kg^{-1}), which was washed with 80% ethanol before removing oligosaccharides. Following incubation for 20 min at 37 °C, the reactions were terminated by adding 5 mL of cold borate buffer (100 mM, pH 9.0). Then, 1 mL 2-cyanoacetamide (20 g kg^{-1}) were added. The sample was combined, and immersed