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Postharvest senescence of florets from primary and secondary broccoli inflorescences

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ABSTRACT

The shelf-life of fresh-cut vegetables may be markedly affected by the type and quality of the raw materials. In this work we evaluated the influence of the type of inflorescence used for processing (primary and lateral) on the postharvest senescence of refrigerated fresh-cut broccoli. Florets from primary and lateral heads were cut and washed with chlorinated water, rapidly cooled to 4 °C, packed in plastic trays covered with perforated PVC and stored at 4 °C for 0, 14 or 21 d. During storage we evaluated floret deterioration, respiration rate, weight loss, color, chlorophyll content, sugars (glucose, fructose and sucrose), antioxidant capacity against $ABTS^{\bullet+}$ and $DPPH^{\bullet}$ radicals, ascorbic acid and Folin–Ciocalteu-reacting substances. Florets from lateral inflorescences were more perishable than fresh-cut broccoli obtained from primary heads. Terminal florets retained higher chlorophyll levels and showed delayed yellowing. Already at harvest primary-broccoli showed lower respiration rate. Florets form terminal heads showed lower weight and sugar loss during storage and maintained higher visual quality throughout the storage period at 4 °C. The inflorescence type also had large impact in the initial level of antioxidants as well as in their metabolism during storage. This information may be useful for vegetable processors.

1. Introduction

Changing life-styles in the last decades have raised the demand for healthy, convenient, additive-free, safe and nutritious foods (James and Ngarmsak, 2010). The fresh-cut sector has responded to these demands and has consequently been playing an increasing role in fruit and vegetable marketing in the United States, Europe and Asia (Cook, 2009; James and Ngarmsak, 2010). Apart from offering consumers a range of options in a single package, fresh-cut vegetables may reduce food preparation time and wastage at the household level.

It is accepted that the quality and shelf-life of fresh-cut vegetables may be markedly affected by the type and quality of the raw materials. The quality of green vegetables is determined by a number of preharvest conditions ranging from cultural practices, irrigation and fertilization to environmental conditions (Kader, 2008; Colelli and Elia, 2009). Water salinity and plant density were shown to affect the quality of fresh-cut lettuce (Scuderi et al., 2009; Luna et al., 2013). Nutrient supply has also been shown to play a crucial role for fresh-cut quality and shelf-life (Konstantopoulou et al., 2010; Bonasia et al., 2013). The genotype, harvest time and organ location plant have also been found to determine vegetables postharvest responses (Singh et al., 1992; Clarkson et al., 2005).

Broccoli has been traditionally marketed in the form of whole inflorescences. The shelf-life of intact broccoli may vary from 12 to 25 d at 4 °C depending on cultivar (Cantwell and Suslow, 1997). Broccoli has gained popularity due to the association of its consumption with the prevention of some types of cancer (Jeffery et al., 2003). In recent years minimally-processed broccoli florets have been offered as a "healthy snack" (Lemoine et al., 2010; Lemoine et al., 2010). Broccoli primary heads are harvested in an immature stage, before flower opening, when still dark green and firm (Hasperué et al., 2011). However, after harvest secondary lateral heads are induced. These smaller lateral inflorescences can

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account for as much as 30% of total yield and could be used for fresh consumption or processing (Rosa et al., 2002). Some studies have started to characterize primary and lateral broccoli. Calcium and sulfur levels were higher in the secondary inflorescences (Rosa et al., 2002). In contrast, the levels of sugars in terminal and lateral heads varied depending on the cultivar (Rosa et al., 2001). A survey of 11 broccoli cultivars produced in winter and summer showed that in most cases lateral heads were richer in total glucosinolate contents (Rosa and Gomes, 2001). Whether or not the floret source could also impact fresh-cut product postharvest responses has not been studied. The objective of this work was to perform a comparative analysis of the postharvest senescence of fresh-cut broccoli obtained from terminal and lateral inflorescences.

2. Materials and methods

2.1. Plant material and storage conditions

Broccoli (*Brassica oleracea* var. *Italica* cv. Legacy) heads were harvested at commercial maturity from a commercial grower in La Plata, Argentina (34° 59′S and 58° 3′W). Thirty primary (terminal) and 30 secondary heads were harvested at 8:00 AM and carried immediately to the laboratory. The inflorescences were separated into florets with stems and immersed in chlorinated water (sodium hypochlorite, 150 mg L^{-1}) for 5 min. Approximately 110–140 g of broccoli florets were placed in plastic trays (around 15 florets per tray), wrapped with perforated PVC and stored in darkness at 4 °C for 0, 14 and 21 d. Four trays were prepared for each inflorescence type and sampling date. Samples were taken at the aforementioned times and immediately evaluated or frozen in liquid nitrogen and stored at −80 °C until analysis. The whole experiment was repeated twice with similar results.

2.2. Surface color

Color (L^* a^* b^* system) was evaluated with a colorimeter (Minolta CR-400, Osaka, Japan) using D65 illuminant lighting conditions during the period of storage. Ten measurements were done per tray, inflorescence type and storage time. The Hue angle (h°) was calculated as $h^\circ = \tan^{-1}(b/a)$ when a and $b > 0$ or $h^\circ = 180^\circ + \tan^{-1}(b/a)$ when $a < 0$ and $b >$ 0; and chroma was calculated as $(a^2 + b^2)^{1/2}$.

2.3. Chlorophylls

Frozen samples were processed in a mill and approximately 0.4 g of the obtained powder was added to 2.5 mL of acetone/water (80/20) and homogenized. The homogenate was vortexed for 15 s and centrifuged at 5500 × g for 5 min. The supernatant was collected and the extraction procedure was repeated with the addition of 2.5 mL of acetone/water (80/20). Chlorophyll content was determined spectrophotometrically according to Lichtenthaler (1987) and expressed as mg kg^{-1} of chlorophyll on a fresh weight basis. Three independent samples consisting of five florets each were ground and used for analysis.

2.4. Weight loss and respiration rate

The broccoli trays were weighed during storage period and weight loss (WL) was calculated from initial (IW) and final weights (FW) as $WL(\%) = (IW - FW/IW) \times 100$.

For respiration measurements, broccoli florets held at 20 °C for 2 h until reaching room temperature, weighing approximately 150 g were placed in a 3 L flask, sealed and incubated for 15 min at 20 °C (to prevent CO_2 levels over 1% which would affect the respiration rate). CO_2 concentration in the headspace was determined using an infrared analyzer (Alnor, CompuFlow Model 8650 MN, USA). Results were expressed as rate of CO_2 evolution in mg kg^{-1} s^{-1}. Three samples from different florets were analyzed for each inflorescence type and sampling date.

2.5. Deterioration index

Samples were visually evaluated on individual trays based on surface yellowing, dehydration symptoms, and decay by using an intensity scale (0 = excellent quality without changes relative to day 0; 1 = good quality with minor changes relative to day 0; 2 = samples with up to 1 senescent, dehydrated or yellow floret per tray, 3 = samples with up to 3 senescent, dehydrated or yellow florets per tray, 4 = samples with up to 5 senescent, dehydrated or yellow florets per tray, 5 = unfit for being marketed, 6 = unfit for being marketed and with fungal decay. The deterioration index (DI) was calculated as follows:

DI = Σ (Injury level × Number of trays in this level)/Total number of trays. Four trays of primary and secondary inflorescences for each sampling time were taken.

2.6. Ascorbic acid

Frozen samples were processed in a mill and approximately 0.6 g of the obtained powder was homogenized with 2.5 mL of 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. A high performance liquid chromatograph (Waters 1525 Binary HPLC Pump) fitted with a photo diode array detector and a C_{18} column (4.6 × 150 mm, 5 μm, Waters Corp., USA) was used for ascorbic acid (AA) determination. The mobile phase was 0.5% m/v metaphosphoric acid/acetonitrile (93/7), at an isocratic flow rate of 16.7 μL s^{-1}. Detection was performed at 245 nm. For identification and quantitation a standard ascorbic acid solution was employed. Results were expressed as mass of AA on a fresh weight basis, mg kg^{-1}. Three extracts per sample and storage time were obtained and measurements were done in triplicate.

2.7. Sucrose, glucose and fructose

Frozen broccoli florets were ground in a refrigerated mill and 0.6 g of the obtained powder were homogenized with 5 mL of ethanol and vortexed for 1 min. The mixture was centrifuged at 5580 × g for 10 min at 4 °C; the supernatant was recovered and filtered through 0.2 μm RC membrane (Cole-Parmer, USA). Soluble sugars were determined by using a high-pressure liquid chromatography system equipped with a refractive index detector (Waters, IR 2414) and a Hypersil Gold Amino column (4.6 × 250, 5 μm, Thermo Sci. USA). An isocratic flow rate of 16.7 μL s^{-1} of acetonitrile/water (70/30) was used for analysis. Results were expressed on a fresh weight basis as mg kg^{-1}. Three extracts per sample and storage time were obtained and measurements were done in triplicate.

2.8. Folin–Ciocalteu-reacting substances

Approximately 50 g of frozen broccoli florets were ground in a mill and 0.6 g of the resultant powder was homogenized in 5 mL of ethanol as described above. A sample of the crude extract (50 μL) was added to 950 μL of distilled water and 50 μL of 1:1 diluted Folin–Ciocalteu reagent. After 3 min, 100 μL of a solution containing 20% (m/v) Na_2CO_3 in 0.1 mol L^{-1} NaOH were added, and incubated at 25 °C for 90 min (Singleton et al., 1999). The absorbance was measured at 760 nm and the total phenolic content was calculated using gallic acid (GA) as standard. Results