Postharvest Biology and Technology 138 (2018) 125–133

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Effect of temperature on glucosinolate content and shelf life of ready-to-eat broccoli florets packaged in passive modified atmosphere

Erika Paulsen[a,*], Sofía Barrios[a], Nieves Baenas[c], Diego A. Moreno[c], Horacio Heinzen[b], Patricia Lema[a]

[a] Instituto de Ingeniería Química, Facultad de Ingeniería, Universidad de la República, Julio Herrera y Reissig 565, Montevideo, Uruguay
[b] Cátedra de Farmacognosia y Productos Naturales, Departamento de Química Orgánica, Facultad de Química, Universidad de la República, General Flores 2124, Montevideo, Uruguay
[c] Phytochemistry Laboratory, Department of Food Science and Technology, CEBAS-CSIC, P.O. Campus Universitario de Espinardo-Edificio 25, E-30100, Espinardo, Murcia, Spain

ARTICLE INFO

Keywords:
Storage
Fresh cut
Minimally processed
Glucosinolates
Antioxidant capacity

ABSTRACT

Ready-to-eat fruit and vegetables comprise a group of increasingly demanded value-added products. Broccoli is a highly perishable vegetable with unique nutritional characteristics. Development of minimally processed broccoli products demands varietal-specific knowledge as to which are the packaging conditions that preserve quality throughout shelf life. 'Legacy' cultivar broccoli florets were washed, disinfected, packaged in polypropylene and stored at 4, 8 and 15 °C for 21 d. Weight loss, internal atmosphere composition, respiration rate, color, texture, glucosinolate content, antioxidant capacity (AOC) and sensory attributes were evaluated throughout storage time. Results showed that 4 °C helped preserve sensory quality, texture, total glucosinolate content and AOC for 21 d. Temperature fluctuations reaching 15 °C resulted in loss of total glucosinolate content and unacceptable sensory quality. MAP helped mitigate temperature effects, especially at 8 °C. MAP is therefore an appropriate technology which can be applied to extend the shelf-life of ready-to-eat broccoli florets.

1. Introduction

Broccoli is a vegetable that is increasingly recognized as a valuable nutritional source of phytochemicals, including glucosinolates and phenolics, antioxidants such as vitamins, and dietary essential minerals (Jia et al., 2009; Moreno et al., 2006; Pérez-Balibrea et al., 2011). However, it is an extremely perishable vegetable due to its high respiration rate. Moreover, when broccoli is processed to be marketed as a ready-to-eat fresh vegetable, unit operations exerted such as washing, cutting and packaging promote a faster physiological deterioration and hastened biochemical changes (Lucera et al., 2011), impacting on product's sensory and nutritional quality.

Glucosinolates (GLS) are a diverse class of secondary plant metabolites and are mainly found in *Brassica* vegetables, including broccoli. These compounds share a similar chemical structure consisting of a d-thioglucose group, a sulphonated oxime group and a variable side chain derived from aminoacids (Moreno et al., 2006). GLS and their metabolic breakdown products (isothiocyanates) have gained an important interest in recent years since their consumption has been related to reduction of risk of suffering certain type of chronic diseases, including cancer (Dominguez-Perles et al., 2014; Hennig et al., 2014).

From a technological point of view, application of preservation technologies is essential for preserving minimally processed broccoli's sensory and nutritional quality during postharvest and extending product shelf life. Application of modified atmosphere packaging (MAP) has demonstrated to be a promising technology for this purpose (Sandhya, 2010). MAP technology consists in packaging horticultural products in permeable films. Inside the package, a modified atmosphere in terms of O_2 and CO_2 concentration with respect to normal air will be generated by the interplay of mainly three factors: product respiration, package permeability and storage temperature. As a result of this dynamic process, internal package O_2 concentration will decrease and internal CO_2 concentration will increase. These modified atmospheres help extend product shelf life because reduced O_2 levels and increased CO_2 levels slow down product respiration rate, thus retarding product senescence and deterioration and limiting microbial growth (Robertson, 2006). In MAP technology, temperature is one of the most important factors affecting produce phytochemical content and shelf life (Fonseca et al., 2002). Storage temperature was shown to have significant impact on GLS content in broccoli with stable levels of total

* Corresponding autor.
E-mail address: erikap@fing.edu.uy (E. Paulsen).

https://doi.org/10.1016/j.postharvbio.2018.01.006
Received 2 June 2017; Received in revised form 9 January 2018; Accepted 9 January 2018

GLS during storage at 4 °C and declining levels observed during storage at 20 °C (Rangkadilok et al., 2002; Rodrigues and Rosa, 1999). However, conflicting evidence has been presented by other authors, who have reported either no change in total GLS levels (Song and Thornalley, 2007; Winkler et al., 2007) or reduction in total GLS (Vallejo et al., 2003) in broccoli during storage at both low and high temperatures. Recently, it has been shown that stress factors (including temperature) can induce activation of primary and secondary metabolism of broccoli, increasing GLS content during storage (Villarreal-García et al., 2016). In this way, effect of storage temperature on GLS content in broccoli has not been unequivocally reported nor fully understood yet (Rybarczyk-Plonska et al., 2016). There is still lack of knowledge regarding how postharvest storage conditions affect physicochemical and nutritional quality of ready-to-eat broccoli and which are the conditions that can improve its overall quality and shelf life. Further characterization of different broccoli varieties in terms of their aptitude for minimal processing is also needed. The aim of the present study was to evaluate the effect of storage time and temperature on glucosinolate content and physicochemical and sensory quality of ready-to-eat broccoli florets (cv. Legacy) packaged in passive modified atmosphere.

2. Materials and methods

2.1. Plant material and experimental design

Broccoli heads (*Brassica oleracea* L. [Italica Group] cv. Legacy, commercial cultivar) harvested at commercial maturity, were obtained from a grower in Canelones, Uruguay. Within 24 h after harvest, broccoli heads were transported to Facultad de Ingeniería in Montevideo, Uruguay. Broccoli heads (15–20 cm diameter each), free of visual defects, were chosen and the inflorescences were separated into florets with stems (3–4 cm diameter each floret). Florets were washed, sanitized in 100 mg L^{-1} NaClO solution for 5 min, rinsed, centrifuged and packaged under passive modified atmosphere. Approximately 250 g of broccoli florets were placed in plastic trays wrapped with perforated polypropylene bags (30 × 25 cm, 30 µm thickness). Bags were sealed using a Supervac GK105/1 packaging machine (Wien, Austria) with air injection. Samples were stored in darkness at 4, 8 and 15 °C for 21 d. At preselected storage times (0, 7, 14 and 21 d), three trays were sampled for each temperature assayed. Different packages were used at each sampling point. Samples were immediately evaluated in the case of physical and sensory attributes or freeze – dried for chemical analysis. The following quality attributes were measured throughout shelf life: internal atmosphere composition, weight loss, instrumental color, instrumental texture, respiration rate, glucosinolate content, antioxidant capacity and sensory attributes.

2.2. Internal atmosphere composition

O_2 and CO_2 concentration inside packages were measured using a gas analyzer (OXYBABY® 6.0, Witt, Germany), extracting a 6 mL sample directly from the package. Results were expressed as partial pressure (kPa) of O_2 and CO_2 inside the bags.

2.3. Weight loss

Each bag was individually weighted the day of its preparation (day 0) and at each sampling time. Weight loss was calculated as percentage (%) of initial weight.

2.4. Instrumental color

CIE Lab color space parameters (L*, a*, b*, C^*_{ab} and h_{ab}) were determined using a colorimeter - spectrophotometer CM 600 d (Konica Minolta, Japan). Recommendations of Commission Internationale de L'Eclariage (CIE, 2004) were followed: 10° Standard Observer angle and Standard Illuminant D65 were used. Measurement area was 8 mm and equipment was calibrated using a standard white reflector plate. For each experimental unit, five florets were measured and within each floret, five measurements were taken at different positions.

2.5. Instrumental texture

Texture analysis was done using a TA.XT2i Texture Analyzer (Stable Micro Systems Ltd., UK). A 50 kg load cell was calibrated with a 5 kg weight. Texture Analyzer was equipped with a 3 mm diameter cylinder probe in order to evaluate hardness of broccoli florets' stalks through penetration test. Penetration test was performed on broccoli stalks cut one centimeter thick. Stalks were penetrated longitudinally. Test conditions used for measurements were: 2.0 mm s^{-1} pre-test speed, 1.0 mm s^{-1} test speed, 5.0 mm s^{-1} post-test speed, 5 mm penetration distance. Data of force (N) versus time (s) were registered using Texture Exponent Software (Version 3.2, Stable Micro Systems Ltd.). Hardness value was determined as maximum force registered in the force vs time curves. Measurements were made on five broccoli stalks per experimental unit.

2.6. Respiration rate

Respiration rate was determined as O_2 consumption rate using the closed system method (Barrios et al., 2014; Fonseca et al., 2002). Broccoli florets were transferred from package to measuring system and were equilibrated for 2 h at test temperature. A weighted quantity (250 ± 10 g) of broccoli florets was enclosed in hermetic stainless steel reactors (2.5 L capacity) under temperature controlled conditions (18 ± 1 °C). Temperature and relative humidity inside reactors were registered using iButtons (Maxim Integrated Products, Inc., California, USA). Monitoring of O_2 evolution inside reactors was done for a time span of 10 h, assuming that in this time product did not age significantly, and O_2 concentration did not vary enough as to influence respiration rate. Measurements were done in triplicate for each storage condition. O_2 concentration in reactors' headspace was determined via non-invasive measurements taken with O_2 optic mini-sensors (PreSens GmbH, Regensburg, Germany). Data acquisition was done automatically every 1 min by the Oxy4v2_11FB software (PreSens GmbH, Regensburg, Germany). Temperature compensation was implemented for acquired data. O_2 measurements taken with O_2 mini-sensors were previously validated with gas chromatography measurements. Respiration rate was determined as consumption rate of O_2 (RRO2) calculated using Eq. (1):

$$RRO2 = \left(\frac{\partial p_{O_2}}{\partial t}\right)\Bigg|_{t=0} \cdot V_{free} \cdot \frac{1}{m} \cdot \frac{1}{RT} \quad (1)$$

where RRO2 is expressed µmol kg^{-1} s^{-1}, p_{O_2} stands for O_2 concentration inside reactor (kPa), t is time (s), m is product mass (kg), V_{free} is the free volume inside container (L), R is universal gas constant and T is temperature inside reactors (K). V_{free} was calculated considering reactors' total volume (L), product mass enclosed and broccoli density as obtained from mass and volume measurements.

2.7. Glucosinolate content

2.7.1. Sample extraction

Sample extraction was carried out according to Baenas et al. (2016). Freeze-dried samples (50 mg) were extracted with 1 mL of methanol (70% v/v) and heated at 70 °C for 30 min in a heating bath. Samples were shaked every 5 min using a vortex stirrer. After heating, samples were centrifuged (17500 × *g*, 15 min, 4 °C). Supernatants were collected and methanol was completely removed using a rotary evaporator. Dry material obtained was re-dissolved in ultrapure water to