LWT - Food Science and Technology 44 (2011) 277–283

Contents lists available at ScienceDirect

LWT - Food Science and Technology

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

Optimum controlled atmospheres minimise respiration rate and quality losses while increase phenolic compounds of baby carrots

Adriano D.N. Simões [a], A. Allende [b], Juan A. Tudela [b], Rolf Puschmann [a], Maria I. Gil [b,*]

[a] Departamento de Biologia Vegetal, Universidade Federal de Viçosa, Minas Gerais, Brazil
[b] Research Group on Quality, Safety and Bioactivity of Plant Foods, CEBAS-CSIC, P.O. Box 164, Espinardo, Murcia, 30100, Spain

ARTICLE INFO

Article history:
Received 29 April 2009
Received in revised form
2 June 2010
Accepted 2 June 2010

Keywords:
Daucus carota
Minimally processed
Fresh-cut
Storage conditions
Vitamin C
Carotenoids
Phenolic compounds
Antioxidant constituents
Fruit and vegetables

ABSTRACT

Baby carrot is a very perishable product mainly due to the abrasion of the cylindrical carrot root segments. The influence of four different controlled atmospheres (CA) (air, 2 kPa O_2 + 15 kPa CO_2, 5 kPa O_2 + 5 kPa CO_2 and 10 kPa O_2 + 10 kPa CO_2) was studied to maintain quality and prolong the shelf life of baby carrots. Respiration rate (RR), the content of vitamin C, carotenoids and phenolics by HPLC as well as the sensory quality of baby carrots during storage at 4 °C were evaluated. The lowest RR was observed in baby carrots stored under CA containing the lowest O_2 concentrations. Baby carrots under low O_2 atmospheres preserved the highest vitamin C content, as well as the individual carotenoids. The wound-induced phenolic compounds, mainly trans chlorogenic acid, increased two fold in baby carrots stored under 5 kPa O_2 + 5 kPa CO_2. In general, CA maintained the overall visual quality of baby carrots up to 8 days. Controlled atmosphere of 5 kPa O_2 + 5 kPa CO_2 can be recommended as an optimum atmosphere to maintain quality of baby carrots, increasing bioactive compounds such as chlorogenic acid and avoiding anaerobic fermentation in case of temperature abuse.

1. Introduction

The relationship between a diet rich in vegetables and the reduction of several chronic diseases such as arteriosclerosis and cancer has been well documented in the last decade (Gundgaard, Nielsen, Olsen, & Sorensen, 2003; Hashimoto, Kawamata, Usui, Tanaka, & Uda, 2002; Kris-Etherton, Etherton, Carlson, & Gardner, 2002). In general, the beneficial effects associated with the Mediterranean diet are attributed to antioxidant compounds, such as vitamins C and E, carotenoids and phenolic compounds, especially flavonoids, abundantly present in fruits and vegetables (Podsedek, 2007). However, the antioxidant content of fruits and vegetables can be affected by different factors, including storage conditions (Klaiber, Baur, Koblo, & Carle, 2005). Postharvest technologies aim to maintain the level of these antioxidant constituents during product shelf life (Rico, Martín-Diana, Barat, & Barry-Ryan, 2007). Modified atmosphere has been one of the postharvest tools to maintain produce quality. However, experiments to determine the optimum package design require in the first instance a study under controlled atmospheres (CA) as a guide to evaluate their influence under controlled conditions.

The consumption of fresh-cut carrots has steadily increased in popularity in the last few years, particularly baby carrots which is one of the most popular products. Although fresh whole carrots are not a very perishable product, baby carrots suffer from the rapid deterioration during storage. Baby carrots, which are prepared by peeling the outer layer of the carrot roots, are susceptible to a variety of physiological changes that reduce their quality (Li & Barth, 1998). The main problems that limit the shelf life of baby carrots to 4 or 5 days are; high respiration rate (RR), development of off-flavours, acidification, loss of firmness, discoloration and microbial spoilage (Barry-Ryan & O'Beirne, 2000; Barry-Ryan, Pacussi, & O'Beirne, 2000). Minimal processing not only affects the sensory quality of baby carrots, but can also reduce the content of bioactive compounds such as vitamin C, carotenoids and phenolics. In fact, Reyes, Villareal, and Cisneros-Zevallos (2007) observed that the vitamin C content of baby carrots was significantly lower when compared to the intact tissue. Additionally, carotenoids, abundantly present in the phloem tissue of carrots, are more susceptible to degradation after the removal of the epidermis and xylem tissues during peeling (Howard & Dewi, 1996).

It is well known that the quality of minimally processed products can be maintained by cold storage and CA as a way to minimize

* Corresponding author. Tel.: +34 968 396 315; fax: +34 968 396 213.
E-mail address: migil@cebas.csic.es (M.I. Gil).

0023-6438/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.lwt.2010.06.002

the wound-induced reactions. Generally, concentrations of 2–5 kPa O_2 and 5–10 kPa CO_2 are recommended to extend the shelf life of minimally processed products. The beneficial effects of controlled and modified atmospheres on the quality and phytochemical content have been studied mainly in leafy vegetables (Fonseca, Oliveira, Brecht, & Chau, 2003; López-Gálvez, Saltveit, & Cantwell, 1996; Martínez-Sánchez, Marin, Llorach, Ferreres, & Gil, 2006). Some of these studies demonstrated that CA containing low O_2 concentrations (2–5 kPa) and high CO_2 levels (10 kPa) maintained the sensory quality as well as the content of vitamin C and flavonoids while increasing the shelf life of lettuce and rocket leaves (López-Gálvez et al., 1996; Martínez-Sánchez et al., 2006). In the case of minimally processed carrots; slices, sticks and shred, have been the most common types of cutting in scientific investigation (Alasavar, Al-Farsi, Quantick, Shahidi, & Wiktorowiez, 2005; Babic, Amiot, Nguyen-the, & Aubert, 1993; Izumi, Watada, Nathanee, & Douglas, 1996). These studies demonstrated that temperature and gas composition have a great influence on the sensory quality of carrot; reducing decay, weight loss, white discoloration and microbial growth. In shredded carrots, CA of 2–10 kPa O_2 combined with 10–40 kPa CO_2 minimized sugar loss during storage (Carlin, Nguyen-the, Chambroy, & Reich, 1990). However, exposure of fresh fruits and vegetables to O_2 levels below, or CO_2 levels above their tolerance limits, causes stresses to plant tissues which are manifested by various symptoms, such as aggravation of certain physiological disorders, a shift from aerobic to anaerobic respiration and, consequently, ethanol and acetaldehyde accumulation causing off-flavours and tissue damage (Lee, Arul, Lencki, & Castaigne, 1995). It was also reported that excessively low O_2 levels decreased synthesis of bioactive compounds such as phenolic compounds (Alasavar et al., 2005; Babic et al., 1993).

Studies on baby carrots have determined optimum atmosphere levels of low O_2 (2–5 kPa) and high CO_2 (15–25 kPa) without analyzing their impact in the content of bioactive compounds such as vitamin C, carotenoids and phenolic compounds (Alasavar et al., 2005; Babic et al., 1993; Carlin et al., 1990; Izumi et al., 1996). Recently, it has been demonstrated that cold storage and moderate modified atmospheres enhance the phenolic content of carrot sticks (Klaiber, Baur, Koblo, et al., 2005; Simões, Tudela, Allende, Puschmann, & Gil, 2009). The aim of this study was to determine, for the first time, the effect of different O_2 and CO_2 levels on the respiration rate, phytochemical content and sensory quality of baby carrots.

2. Materials and methods

2.1. Plant material and storage conditions

Commercially prepared baby carrot samples were collected from a salad manufacturer on the day of processing and transferred to CEBAS-CSIC (Murcia, Spain) on ice in insulated boxes avoiding direct contact between the product and the ice. Damaged carrots and those with defects were removed. Selected baby carrots were stored in darkness overnight at 5 °C and 90% relative humidity (RH). The next day, 200g of baby carrots were stored under different CA conditions in 750 mL glass jars connected to a flow-through system providing humidified air at a constant flow rate (Martínez-Sánchez et al., 2006). Four CA were applied: (**1**) 2 kPa O_2 + 15 kPa CO_2; (**2**) 5 kPa O_2 + 5 kPa CO_2; (**3**) 10 kPa O_2 + 10 kPa CO_2 and (**4**) air (21 kPa O_2 + 0.04 kPa CO_2). The jars were stored in darkness at 4 °C for up to 12 days.

2.2. Respiration rate

Respiration rate (RR) of baby carrots stored under different CA was determined by the closed method (Kader, 1989), based on the CO_2 accumulation inside the jars. To allow the CO_2 accumulation, the glass jars were hermetically sealed for 4 h for those atmospheres containing 2 kPa O_2 + 15 kPa CO_2, 5 kPa O_2 + 5 kPa CO_2 and 10 kPa O_2 + 10 kPa CO_2 and 0.5 h in the case of air. CO_2 production of baby carrots was measured by an infrared gas analyzer (Horiba Via 510, Horiba Instruments Co., Irvine, Calif, USA). Samples of 1 mL of the headspace were periodically monitored during 11 days of storage at 4 °C.

2.3. Extraction and analysis of ascorbic and dehydroascorbic acids

Ascorbic acid (AA) and dehydroascorbic acid (DHA) contents were determined as described by Zapata and Dufour (1992). Ten grams of fresh tissue were used for the extraction. The HPLC system, standard solutions, column conditioning, and derivatization procedures have been previously described by Gil, Ferreres, and Tomás-Barberán (1999). The vitamin C content was calculated by the addition of AA and DHA, and the results were expressed as mg per 100 g fresh weight (fw).

2.4. Extraction and analysis of carotenoids

The procedure used was as described by Minguez-Mosquera and Garrido-Fernandez (1989) with some modifications (Marín, Ferreres, Tomás-Barberán, & Gil, 2004). Five grams of fresh tissue were extracted with 5 mL of MeOH and filtered with acetone (50 mL) until no colour was observed. β-Apo-8′ carotenal (Sigma–Aldrich) was used as the internal standard. Pigments were transfer to ethyl ether adding 10 g/L NaCl. Carotenoids were evaluated by HPLC equipped with a pump (model L-6200, Merck-Hitachi) and photodiode array UV/vis detector (SPD-M6A, Shimazu, Japan). Separations were achieved on a LiChrocart C_{18} column (250 mm × 4 mm i.d., 5 μm particle size) (Merck) using a gradient program previously described (Minguez-Mosquera & Hornero-Mendez, 1993). Elution was performed at a solvent flow rate of 1.5 mL min^{-1} with an injection volume of 20 μL and detection at 426 nm for β-apo-8′ carotenal, 440 nm for α-carotene and 453 nm for β-carotene. β-Carotene was used as the external standard for quantification. The concentrations were calculated and expressed as μg of β-carotene per 100 mg fw.

2.5. Extraction and analysis of phenolic compounds

Freeze-dried carrot samples (1 g each) were homogenized using an Ultra Turrax (Ika, Staufen, Germany) in 20 mL of extraction solution (acetone/H_2O/acetic acid; 70/29.5/0.5 v/v/v) for 1 min at 4 °C. Homogenates were sonicated (5510E-MTH, Branson Ultrasonic Coorporation, USA) at 37 °C for 10 min and centrifuged at 4000 g for 15 min (Centromix centrifuge, Selecta, Barcelona, Spain). Supernatants were concentrated under reduced pressure at 35 °C to remove acetone. The aqueous fraction was dissolved in 10 mL of H_2O and filtered through a C_{18} Sep-Pak cartridge (Waters Corp, Milford, MA), which was previously activated with MeOH followed by H_2O and air. Phenolic compounds were absorbed onto the column, while sugars, acids and other water-soluble compounds were eluted with 10 mL of H_2O. Phenolic compounds were then recovered with 1.5 mL of MeOH and passed through a 0.45 μm pore filter (Millex HV13, Millipore, Bedford, MA). Samples of 20 μL were analyzed by HPLC (Merck Hitachi, Tokyo, Japan) equipped with a pump (model L-7100) and a photodiode array UV/vis detector (model L-7455). The samples were injected by an autosampler (model L-7200). The separation was achieved on a reversed phase Mediterranea sea_{18} column (250 mm × 4.6 mm i.d., 5 μm, Teknokroma, Barcelona, Spain) with H_2O:formic acid (95:5, v:v) (A) and MeOH:formic acid (95:5, v:v) (B) as the mobile phases. The