Postharvest Biology and Technology 58 (2010) 247–253

Contents lists available at ScienceDirect

Postharvest Biology and Technology

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

Antioxidant phytochemicals in fresh-cut carrot disks as affected by peeling method

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ARTICLE INFO

Article history:
Received 21 July 2009
Accepted 30 July 2010

Keywords:
Antioxidant
Phytochemical
Fresh-cut
Minimally processed
Fruit
Vegetable

ABSTRACT

In order to investigate the effects of process severity, the influence of peeling methods of different severities on the retention of antioxidant phytochemicals in carrot disks was examined. Carrots were abrasion peeled using either fine or coarse carborundum plates or peeled manually using a hand-held peeler. They were subsequently cut into disks, packaged and stored for 8 d at 4 °C. Vitamin C (ascorbic acid and dehydroascorbic acid), total phenols, total antioxidants, total carotenoids, colour and pH were measured on production day and throughout the storage period. Antioxidants differed in their response to severity of processing. Initially, machine peeling resulted in a greater accumulation of phenolic compounds and increased total antioxidant activity compared to hand peeled carrot disks. However, at the end of storage no significant ($P > 0.05$) effects of peeling method were observed on the levels of total phenolics and total antioxidants. Total carotenoids were also significantly affected by peeling method with hand peeled carrot disks having significantly ($P \leq 0.05$) higher levels of total carotenoids than coarse peeled carrot disks throughout the storage period. Ascorbic acid was the antioxidant most affected by severity of peeling method. As severity increased there was greater loss of ascorbic acid.

1. Introduction

The positive association between consumption of fruits and vegetables and lower risk of cardiovascular disease, cancer, etc., has been described by many researchers (Steinmetz and Potter, 1996; Joshipura et al., 1999). It has been proposed that antioxidant compounds in fruits and vegetables reduce the risk of these chronic diseases by reducing free-radical mediated damage (Southon, 2000). Fruits and vegetables are rich in antioxidant phytochemicals including vitamin C, phenolic compounds and carotenoids (Heinonen, 2002). Carrots (*Daucus carota*) are among the most popular root vegetables and have been identified as the main dietary sources of α- and β-carotene in most European countries (O'Neill et al., 2001). The predominant carotenoid identified in carrot cultivars is β-carotene (Alasalvar et al., 2001). Carrots also contain substantial amounts of vitamin C and phenolic compounds, with chlorogenic acid being the most abundant phenolic compound identified in carrot cultivars (Babic et al., 1993; Klaiber et al., 2005; Kreutzmann et al., 2008).

Due to changes in consumer attitudes in recent years the demand for fresh-cut fruit and vegetable products has increased dramatically. Fresh-cut carrot products such as carrot sticks, disks, batons, shredded carrots, represent an important component of the fresh-cut vegetable industry. Minimal processing of carrots at an industrial scale generally involves initial rinsing, peeling, slicing, washing, packaging and storage (Laurila and Ahvenainen, 2002). As the consumption of these products increases it is important to investigate whether minimal processing may result in losses of these important phytochemicals. Only limited data is available on the effects of minimal processing on antioxidants in carrots. Generally, vitamin C was shown to decrease in fresh-cut carrots during storage at 4 °C (Martin-Diana et al., 2005, 2006; Simões et al., 2009). In contrast, carotenoids were reported to be more stable to processing and storage and can actually increase during storage (Kalt, 2005). During postharvest storage, *de novo* synthesis of carotene in raw whole carrots was previously described (Lee, 1986; Berger et al., 2008). Similarly, Howard et al. (1999) observed an increase in β-carotene in fresh carrots (cooked and uncooked) stored at 4 °C in Ziploc® vegetable bags during the first two weeks of storage. By contrast, studies have reported decreases in total carotenoid content in fresh-cut carrots during cold storage (Martin-Diana et al., 2005, 2006; Ruiz-Cruz et al., 2007). Accumulation of phenolic compounds during storage of minimally processed carrots has been observed by researchers (Babic et al., 1993; Howard and Griffin, 1993; Klaiber et al., 2005). This accumulation of phenolic compounds has been linked with the wound induced synthesis of phenylalanine ammonia-lyase (PAL) (Howard and Griffin, 1993). The use of controlled abiotic stresses, such as wounding, has

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doi:10.1016/j.postharvbio.2010.07.012

been proposed as a tool to enhance phytochemical content of carrots by inducing synthesis/accumulation of phenolic compounds (Cisneros-Zevallos, 2003). Similarly, Simões et al. (2009) reported that the accumulation of phenolics in carrots can be beneficial to enhance phytochemicals of carrot sticks. However, other studies have linked certain phenolic compounds with increased perception of bitter and sour taste in carrots (Lafuente et al., 1996; Talcott et al., 2001; Kreutzmann et al., 2008). An increase in antioxidant capacity of wounded carrot tissue (shredded carrots) and sliced carrots stored at room temperature for 2 d was reported by Fernando Reyes et al. (2007) and Cisneros-Zevallos (2003). Similarly, during cold storage (5 °C), antioxidant capacity of shredded carrots increased for the first 3 d followed by a decrease in activity (Ruiz-Cruz et al., 2007). These researchers have associated the increase in antioxidant capacity they observed with the accumulation of phenolic compounds as a result of wound induced synthesis of PAL.

Minimal processing of certain fruits and vegetables involves peeling to remove unwanted or inedible material, and to improve the appearance of the final product. When carrots are peeled, the periderm layer is removed, exposing inner tissues. The disrupted cell wall becomes susceptible to microbial growth, enzymatic changes, leakage of tissue fluid, dehydration, etc. (Laurila and Ahvenainen, 2002). The preparation of carrots at a domestic level usually involves hand peeling, which causes minimal cellular damage. A key difference in commercial operations is that carrots are subjected to more severe peeling methods. Commercially, carrots are peeled mechanically by abrasion peeling using fine or coarse plates. Severity of processing has been shown to affect vitamin C retention in fresh-cut lettuce, with higher levels retained with less severe slicing methods (Barry-Ryan and O'Beirne, 1999) and less severe washing treatments (Kenny and O'Beirne, 2009). Several studies have reported that as severity of peeling increased, it resulted in a greater surface discoloration and greater loss in the visual appearance of carrots (Bolin and Huxsoll, 1991; Barry-Ryan and O'Beirne, 2000; Cliffe-Byrnes et al., 2007). The peeling treatments used during minimal processing of carrots may affect levels of antioxidant phytochemicals through disruption of cell walls, leakage of tissue fluid or other means. While some data have been published on the effects of minimal processing on phytochemicals in carrots, the effects of peeling severity on phytochemicals in carrots have not been studied. Thus, the objectives of this study were to examine the effects of minimal processing and to compare the effects of peeling methods of different severities on the retention of key antioxidant phytochemicals in carrots.

2. Materials and methods

2.1. Processing and packaging procedures

Irish carrots (Class 1, cultivar Nairobi) were purchased in a local supermarket and stored at 4 °C before processing. Carrots were rinsed briefly prior to peeling in order to remove soil contamination then topped and tailed using a sharp knife. They were either manually peeled using a hand-held peeler (peeling in one direction only) or abrasion peeled using fine or coarse grain peeling plates. Abrasion peeling was carried out for 2 min using a Metcalfe electric abrasion peeler, Model 10 (Metcalfe Catering Equipment Ltd., Gwynedd, Wales, UK) with a load of approximately 0.5 kg of carrots and a water flow rate of 0.05 L s^{-1}. After peeling, carrots were dipped in a 100 mg L^{-1} chlorine solution for 3 min with agitation. The pH of the solution was adjusted to 6.9 using 1 mol L^{-1} HCl. Chlorine dipping was followed by a water rinse (4 °C) for 1 min with agitation to remove residual chlorine and carrots were left drip dry for 15 min in a perforated cage. They were then sliced manually (backed stainless steel razor blades) into disks approximately 6 mm in thickness. Carrot disks were then packaged (~150 g per bag) into pillow pouch packs (10 cm × 25 cm) made from micro-perforated polypropylene film (PA-60, 35 μm thickness, Amcor Flexibles, Bristol, UK), with a permeability to O_2 and CO_2 of 0.694 mL s^{-1} m^{-2}. After heat-sealing under atmospheric conditions products were stored at 4 °C. Antioxidants; vitamin C (L-ascorbic acid and dehydroascorbic acid), total phenols, total carotenoids and total antioxidants were determined on production day (Day 1) and throughout the storage period (Day 4 and Day 8) and were compared to initial values for control unprocessed carrots (Initial). The effects of peeling methods on shelf life parameters such as quality markers (colour measurements and pH) and respiration makers (atmospheric gases in the packs) were also measured during storage. Hand peeling represents the least severe peeling method, whereas coarse abrasion peeling represents the most severe peeling method studied. All experiments were carried out in duplicate (samples were taken from a pool of all the pieces in duplicate storage bags) and replicated three times.

2.2. Gas analysis of package atmosphere

Atmospheric gases in the packs during storage were quantified using a combined O_2, CO_2 and N_2 gas analyser (Gas-space Systech Instruments, UK). Gas samples (50 mL) were withdrawn by piercing the packs with a hypodermic needle through re-sealable polyethylene foam stickers (Farnell Components, Dublin). The gas samples were drawn into the analyser through a flexible probe loop (Systech Instruments, UK) using an airtight syringe.

2.3. L-Ascorbic acid and dehydroascorbic acid

Vitamin C (ascorbic acid and dehydroascorbic acid) was determined using a modification of the HPLC method of Hernandez et al. (2006) as described by Kenny and O'Beirne (2009). Briefly, 25 g of sample was homogenised with 40 mL of chilled 3% meta-phosphoric acid in 8% acetic acid with 1 mM tert-butylhydroquinone (TBHQ). The mixture was then centrifuged and the resulting supernatant was filtered through a 0.2 μm membrane filter prior to HPLC analysis. Analysis was performed on a Waters Sunfire C_{18} 5 μm column (4.6 mm × 150 mm) at 30 °C. The mobile phase was 2% orthophosphoric acid at a flow rate of 8.3 μL s^{-1}. 20 μL of sample was injected onto the column. To determine dehydroascorbic acid, 400 μL of extract was reacted with 400 μL of 50 mM dithiothreitol (DTT) solution for 15 min at room temperature. After the conversion was complete, the sample was injected onto the HPLC column. The dehydroascorbic acid content of the sample was calculated by subtracting the initial ascorbic acid content from the total ascorbic acid content after conversion.

2.4. Total carotenoids

Total carotenoids were extracted by homogenising 5 g of sample with 15 mL acetone/ethanol (1:1) containing 200 mg L^{-1} butylated hydroxytoluene (BHT). Samples were filtered through Whatman No. 4 filter paper in the dark and re-extracted until the residue was colourless. The combined filtrates were brought to 100 mL with extraction solution and the absorbance at 470 nm was measured. The instrument was auto-zeroed against extraction solution. Dilutions were made with extraction solution if necessary. Total carotenoids (fresh weight basis) were calculated according to Gross (1991) and were expressed as mg kg^{-1}.

2.5. Total phenolics

Total phenolics in methanolic extracts (0.33 kg L^{-1}) were determined using the Folin–Ciocalteu assay (Singleton and Rossi, 1965).