Postharvest Biology and Technology 99 (2015) 105–113

Contents lists available at ScienceDirect

Postharvest Biology and Technology

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

Novel approaches to control browning of fresh-cut artichoke: Effect of a soy protein-based coating and modified atmosphere packaging

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ARTICLE INFO

Article history:
Received 7 May 2014
Received in revised form 31 July 2014
Accepted 24 August 2014
Available online 16 September 2014

Keywords:
Minimally processed artichokes
Soy protein edible coating
Superatmospheric oxygen packaging
Antioxidant capacity

ABSTRACT

A soy protein isolate (SPI):beeswax (BW) edible coating was optimized based on BW and L-cysteine (Cys) content to reduce the enzymatic browning of fresh-cut artichoke. The effect of this optimized coating, combined with different modified atmospheres (MA) to extend the shelf-life of cut artichokes, was studied during storage at 5 °C. MAs were obtained by fluxing two gas mixtures (MA-A: 5 kPa O_2 + 15 kPa CO_2; MA-B: 80 kPa O_2) or by conventional passive MA (MA-P). Atmospheric conditions were used as the control. The use of 0.3 g/100 mL Cys combined with a SPI-BW edible coating (40 g/100 g BW, dry basis) helped control enzymatic browning and extended the commercial shelf-life of fresh-cut artichokes to 4 days without providing off-odors. The combination of the coating with MAs did not extend the shelf-life of artichoke slices, but helped maintain the product's antioxidant capacity as compared to the control packaging conditions. Given the high degree of perishability of untreated fresh-cut artichoke, a 4-day commercial period can be considered adequate to distribute sliced artichokes to local markets. However, more studies are required to further extend shelf-life.

1. Introduction

Artichoke cv. Blanca de Tudela is one of the main cultivars grown in Spain. The nutritional benefits and healthy gastronomic properties attributed to artichoke have increased its demand, making it necessary to find appropriate postharvest technologies that extend its distribution range. Processing operations, such as washing, removing external leaves, slicing, and packaging can offer clear advantages for artichoke commercialization. However, these operations induce quality deterioration which results in water loss, softening, microbial contamination, and an increase of respiration and enzymatic activity. Among them, enzymatic browning is the major problem that shortens the shelf-life of fresh-cut artichoke (Amodio et al., 2011). Control of enzymatic browning can be achieved by combining chemical and physical methods, such as the use of antioxidant agents, modified atmosphere packaging (MAP) and proper temperature control.

For 'Blanca de Tudela' artichoke heads, prepared by removing inedible parts (leaves, stalks and outer bracts), the use of MAP with low O_2 (5–10 kPa) and/or elevated CO_2 (5–18 kPa) levels had little or no effect on visual quality if compared to storage under normal atmospheric conditions. In all cases, artichoke heads were considered acceptable after 8–10 days of storage at 4–5 °C (Gil-Izquierdo et al., 2002; Giménez et al., 2003). However, the samples stored under the 2.8 kPa O_2 and 26.3 kPa CO_2 conditions developed off-flavors and presented a shorter shelf-life due to the presence of necrotic zones caused by anoxic conditions (Giménez et al., 2003). Moreover, the microbial counts in those batches with an acceptable sensory quality were above the legal limit, but they were below in the batches where the equilibrium atmosphere was anaerobic. This indicates the need to look for alternatives to achieve acceptable sensory and microbial quality. Some studies have proposed the use of elevated O_2 concentrations as an alternative to low O_2 atmosphere to reduce polyphenol oxidase enzyme (PPO) activity, inhibit anaerobic fermentation, control microbial growth and maintain the fresh-like quality of some fresh-cut products. The effectiveness of superatmospheric O_2 treatment, however, is dependent on factors such as type of commodity, temperature, storage duration, *etc.* (Kader and Ben-Yehoshua, 2000).

The process of cutting edible artichoke heads into wedges and slices significantly increases browning reactions as compared to

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http://dx.doi.org/10.1016/j.postharvbio.2014.08.008
0925-5214/

minimally processed artichoke heads, which further reduces the product's shelf-life. Recent work has found that, from a wide range of compounds, L-cysteine (Cys) and L-cysteine hydrochloride monohydrate were the most effective antioxidants for fresh-cut 'Blanca de Tudela' (Ghidelli et al., 2013) and 'Catanese' (Amodio et al., 2011; Cabezas-Serrano et al., 2013) artichoke, respectively. However, the application of these antioxidants did not sufficiently improve shelf-life for commercialization purposes.

A recent approach to prolong the shelf-life of fresh-cut fruit and vegetables is the use of edible coatings, either alone or combined with MAP. Edible coatings can provide a semipermeable barrier to gases and water vapor by reducing respiration, enzymatic browning and water loss, and their protective function may also be enhanced with the addition of ingredients like antioxidants (Pérez-Gago et al., 2006). The basic ingredients of edible coatings are proteins, polysaccharides and lipids. Del Nobile et al. (2009) showed that although a sodium alginate coating containing citric acid displayed the best performance to extend the shelf-life of artichoke heads, its effect was very limited. Among proteins, soy protein isolate (SPI) coatings have been able to preserve the freshness of apple slices (Kinzel, 1992), control browning in potato slices, and reduce moisture loss in carrots and apple slices (Shon and Haque, 2007). Therefore, the aim of this work was to: (1) develop a SPI-based edible coating containing Cys as an antioxidant and (2) study the combined effect of this coating with MAP, including superatmospheric O_2 conditions, on postponing the enzymatic browning of fresh-cut 'Blanca de Tudela' artichoke prepared as a sliced product.

2. Materials and methods

2.1. Coating formulations

To accomplish the objectives of this work, two experiments were conducted with coating formulations varying in beeswax (BW) (Brillocera, S.A., Valencia, Spain) and L-cysteine (Cys) (Sigma–Aldrich, Barcelona, Spain) content. In the first set of coatings, the BW content of the formulations was 20 g/100 mL (dry basis, db) and the Cys content was 0.1, 0.3, or 0.5 g/100 mL (wet basis, wb). In the second experiment, the coating was 40 g/100 mL (db) BW and 0.3 g/100 mL (wb) Cys. Formulations were prepared with a total solids content of 7.5 and 10 g/100 mL (w/v) for the first and the second experiment, respectively.

To prepare the coatings, aqueous solutions of 5 and 7 g/100 mL (w/v) soy protein isolate (SPI) (SUPRO 760 IP by Solae, Ieper, Belgium) for the first and the second experiment, respectively, were prepared and denatured for 30 min in a 90 °C water bath. Glycerol (Panreac Quimica, S.A., Barcelona, Spain) was added as plasticizer at a SPI to glycerol ratio of 2:1. This ratio was kept constant throughout the study. BW was added to the hot SPI–glycerol mixture at the selected concentration. Samples were homogenized with a high-shear probe mixer (PolyTron, Model PT 2100, Kinematica AG Inc., Lucerne, Switzerland) for 4 min at 30,000 rpm. After homogenization, emulsions were placed in an ice bath to prevent further protein denaturation and to crystallize lipid particles. Finally, the antioxidant was incorporated into the emulsion coating by magnetic agitation.

2.2. Preparation of artichokes

Artichokes (*Cynara scolymus* L., cv. Blanca de Tudela) were purchased at a local market (Valencia, Spain) and were stored at 5 °C for 24 h until processing. After washing, artichoke outer bracts, leaves and stalk were removed. Artichoke hearts were cut into slices (approximately 5 mm wide) using a sharp stainless-steel knife. A maximum of 15 artichokes were processed at the same time to minimize their exposure to oxygen. The whole process was carried out in a temperature-controlled room at 10 ± 1 °C under suitable hygienic conditions.

2.3. Application of edible coatings

Artichoke slices were dipped in the coating solutions and the aqueous solutions of the antioxidant for 3 min. The pHs of the cysteine aqueous solutions and the soy protein isolate (SPI)-based edible coating were 5.7 ± 0.2 and 6.8 ± 0.1, respectively. As a control, samples were dipped in a water solution under similar conditions. An additional control was used in the first experiment by dipping samples in a SPI:BW coating without the antioxidant. After draining and drying under cold conditions, four pieces (80 ± 5 g) were placed on polypropylene trays (17.4 cm × 12.9 cm × 3.6 cm, Ilpra Systems, Barcelona, Spain) and were heat-sealed with microperforated polypropylene film (35 μm P-Plus film, 35 PA 200, Amcor Flexibles, Barcelona, Spain). The polypropylene film was also perforated with a needle (4 perforations of 1 mm in diameter), to ensure that the atmosphere in the tray was not modified and to study only the effect of the treatments. Samples were stored for 7 days at 5 °C.

2.4. Modified atmosphere packaging

Four artichoke slices (80 ± 5 g), either dipped into the SPI + 0.3 g/100 mL Cys coating selected from the second experiment or uncoated (water dipped), were placed on the polypropylene trays and heat-sealed with the 35 μm P-Plus polypropylene film (35 PA 200) that had an O_2 transmission rate of 1,100 $cm^3\ m^{-2}\ day^{-1}$, CO_2 transmission rate of 30,000 $cm^3\ m^{-2}\ day^{-1}$ at 25 °C and 0% RH, and moisture vapor transmission rate of 0.9 $g\ m^{-2}\ day^{-1}$ (Amcor Flexibles, Barcelona, Spain). MA conditions were obtained by flushing trays with two gas mixtures (MA-A: 5 kPa O_2 + 15 kPa CO_2; MA-B: 80 kPa O_2, with the balance being N_2) or by conventional storage under atmospheric conditions with the same film to achieve a passive MA (MA-P). For the control, the film was perforated with a needle (4 perforations of 1 mm in diameter) to ensure that the gas composition within the package remained near ambient oxygen concentration (Control). Thermosealing was done in an ULMA-Smart 300 packing machine (Oñati, Spain). All the samples were stored at 5 °C for quality evaluation.

2.5. Headspace gas analysis

The gas composition in the package headspace during storage was determined in a gas chromatograph (GC valve ThermoFinnigan, Milan, Italy) equipped with a thermal conductivity detector and fitted with a Poropak QS 80/100 column (1.2 m × 0.32 cm). The temperatures of the injector, oven, and detector were 125, 35, and 180 °C, respectively. Helium was used as a carrier gas at a flow rate of 22 mL min^{-1}. One mL of the gas sample from the headspace atmosphere of 5 trays per treatment was measured. Data are expressed in kPa of CO_2 and O_2.

2.6. Color measurement

Color measurements were made with a Minolta colorimeter (Model CR-300, Ramsey, N.Y., USA) on 12 artichoke pieces per treatment and sampling day using the CIE $L^*a^*b^*$ color space. Each measurement was taken randomly at three different locations of each sample piece. A standard white calibration plate was employed to calibrate the equipment.