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Preservation of fresh-cut apple quality attributes by pulsed light in combination with gellan gum-based prebiotic edible coatings

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A B S T R A C T

Pulsed light (PL) has received considerable attention during the last years as a non-thermal method for the superficial decontamination of fresh foods. The aim of the present study was to evaluate the quality attributes of fresh-cut 'Golden Delicious' apples as affected by the combined application of a pulsed light treatment (12 J/cm^2) and a gellan-gum based (0.5% w/v) edible coating enriched with apple fiber. Changes in color, firmness, antioxidant capacity, microbial growth and sensory attributes were determined during 14 days of storage at 4 °C. The combined application of coating and PL treatment retarded the microbiological deterioration of fresh-cut apples and maintained the sensory attribute scores above the rejection limits after prolonged storage. Incorporation of fiber in the coating formulation did not curb the sensory acceptability of apple cubes. Results show that the use of a gellan-gum based coating incorporating apple fiber followed by the application of a PL treatment significantly reduced softening and browning of apple pieces through storage.

Our results reveal that PL treatments applied to gellan-coated fresh-cut apples can be used to decontaminate the cut fruit surface without dramatically affecting its fresh-like quality attributes, thus conferring prebiotic potential and contributing to their shelf-life extension.

1. Introduction

Minimal processing is emerging as an alternative for the provision fresh-like, highly nutritious, convenient and healthful commodities. However, mechanical bruises caused during processing and handling may compromise the safety and appearance of fresh-cut produce, leading to an increase in the respiratory rates and triggering multiple biochemical reactions that underlie microbiological spoilage and quality deterioration (Moreira, Roura, & Ponce, 2011; Oms-Oliu, Soliva-Fortuny, & Martín Belloso, 2008; Ramos, Miller, Brandao, Teixeira, & Silva, 2013; Rico, Martin-Diana, Barat, & Barry-Ryan, 2007).

Different technologies are currently investigated with the aim of decontaminating fresh-cut produce avoiding physical and chemical changes associated to processing. Pulsed light (PL) is a non-thermal technology based on the application of intense pulses of short duration to effectively inactivate microorganisms contained either in light-transmitting media or on opaque surfaces (Gómez-López, Ragaert, Debevere, & Devlieghere, 2007; Marquenie, Michiels, Van Imnpe, & Nicolai, 2003). The treatment has been demonstrated to be cost effective and feasible for the microbial inactivation of both solid and liquid food products (Ramos-Villarroel, Aron-Maftei, Martín-Belloso, & Soliva-Fortuny, 2014). On the other hand, the use of edible coatings is another alternative under investigation to extend the shelf-life of fresh-cut products (Alvarez, Ponce, & Moreira, 2013; Tharanathan, 2003). Gellan gum, a microbial polysaccharide secreted by the bacterium *Pseudomonas elodea*, exhibits unique colloidal and gelling properties and, therefore, good ability to form coatings. These coatings may also serve as carriers of food additives such as antibrowning and antimicrobial agents, colorants, flavors, nutrients, spices and nutraceuticals (Oms-Oliu et al., 2008; Oms-Oliu, Martín-Belloso, & Soliva-Fortuny, 2010; Robles-Sanchez, Rojas-Graü, Odriozola-Serrano, Gónzalez-Aguilar, & Martín-Belloso, 2013). Among these last compounds, fiber was one of the first ingredients associated with health and has been used in food industry since 1980s (MoraesCrizel, Jablonski, Oliveira, Rios, & Rech, 2013). However, the fiber intake in most developed countries fells

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below the levels recommended by health authorities, which usually suggest amounts of total dietary fiber above 25 g/day for adults, of whom one third should be soluble fiber. Fiber incorporation into edible coating formulations may help to meet the daily intakes lagging far below the recommended dietary allowances. Apple dietary fiber, as those obtained from most fruit and vegetable products, possesses a higher soluble portion and better antioxidant properties than fibers from cereal sources (Marín, Soler-Rivas, Benavente-Garcíentala, Castillo, & Pérez-Alvarez, 2007; O'Shea, Arendt, & Gallagher, 2012).

Both PL and edible coatings have been applied to fresh-cut produce with the objectives of reducing the incidence of food-borne pathogens, extending the produce shelf-life, and reducing food quality losses along the distribution chain (Oms-Oliu, Aguiló-Aguayó, Martín-Belloso, & Soliva-Fortuny, 2010; Ramos-Villarroel, Martín-Belloso, & Soliva-Fortuny, 2011). Gellan gum-based edible coatings have been shown to be effective in maintaining the fresh-like quality attributes of fresh-cut fruits such as apples, melons, and pears (Oms-Oliu et al., 2008; Pérez-Gago, Alonso, Mateos, & del Rio, 2005; Rojas-Graü, Tapia, & Martín-Belloso, 2008). As well, the ability of PL treatments to inactivate microorganisms on fresh-cut fruit surfaces has been demonstrated in several published studies (Gómez, Salvatori, García-Loredo, & Alzamora, 2012; Izquier & Gómez-López, 2011; Oms-Oliu, Martín-Belloso, et al., 2010; Ramos-Villarroel et al., 2014). However, so far the combined effect of PL treatments and the use of edible coatings to inhibit microbial growth and to extend the shelf-life of fresh-cut fruits has not been evaluated. Furthermore, the addition of prebiotics for the promotion of health-related properties in such products has been scarcely studied. The main objective of this research was to evaluate the combined application of PL treatments with gellan-gum edible coatings incorporating apple fiber on the quality of fresh-cut apples.

2. Materials and methods

2.1. Materials

'Golden delicious' apples were purchased in a local wholesale distributor (Lleida, Spain) at commercial maturity and stored at 4 ± 1 °C until processing. Food grade gellan gum (Kelcogel®, CPKelco, Chicago, IL, USA) was used as the carbohydrate film-forming biopolymer in coating formulations. Glycerol (Merck, Whitehouse Station, NJ, USA) was added to the coatings as plasticizer. Calcium chloride (Sigma–Aldrich Chemic, Steinhein, Germany) was used to induce crosslinking between the polymer chains. Ascorbic acid (Sigma–Aldrich Chemic, Steinhein, Germany) was added to prevent oxidation of the fruit surface. Dietary fiber concentrate from apple was kindly supplied by the factory Indulleida S. L. (Alguaire, Lleida, Spain). This apple dietary fiber concentrate was the result of drying the washed apple bagasse remaining after apple juice extraction.

2.2. Preparation of film forming and crosslinking solutions

Film-forming solutions were prepared by dissolving gellan (5 g/L water) powders in distilled water and heating at 70 °C while stirring until the solution became clear. Gellan solutions were prepared with and without apple fiber addition (2 g/L). Glycerol was incorporated to the gellan solutions at a concentration of 0.6 g/100 mL. On the other hand, a crosslinking solution was prepared by adding calcium chloride (20 g/L) to an aqueous solution containing 10 g/L ascorbic acid. The concentrations of all ingredients used in these formulations were set up according to previous studies (Rojas-Graü et al., 2008).

2.3. Fruit coating

Apples were gently washed, rinsed and dried prior to the cutting operations. Subsequently, each fruit was peeled, cored and diced into 1 cm-thick cubes. A maximum of four fruits were processed at the same time to avoid oxidation before treatments. Apple dices were first dipped for 2 min into a gellan gum film-forming solution, either with or without added apple fiber. The excess of coating solution was allowed to drip off for 1 min before submerging the fruit pieces for 2 min into the crosslinking dip containing ascorbic acid and calcium chloride. Control samples were dipped only into the crosslinking solution. Ten apple cubes (ca. 60 g) were placed into polypropylene trays of 500 cm^3 (Mcp Performance Plastic LTD, Kibbutz Hamaapil, Israel), which were wrap-sealed with a 64 μm-thick polypropylene film with a permeability to oxygen of 110 cm^3 O_2 m^{-2} bar^{-1} day^{-1} at 23 °C and 0% RH (Tecnopack SRL, Mortara, Italy) using a horizontal thermosealing machine (IlpraFoodpack Basic V/G, Ilpra, Vigenovo, Italy). Trays were heat-sealed and stored at 4 ± 1 °C during less than 30 min prior to PL-processing.

2.4. Pulsed light treatment

The trays containing gellan gum-coated apple cubes were exposed to PL treatments delivered by a XeMaticA-2L device (SteriBeam Systems GmbH, Germany). The system is equipped with two lamps situated at 8.5 cm above and below a quartz sample holder. Experiments were carried out at a charging voltage of 2.5 kV. Each lamp delivered 30 pulses of duration of 0.3 ms with an emitted fluence of 0.4 J/cm^2 at the sample level, thus resulting in an accumulated energy of 12 J/cm^2. The emitted spectrum wavelengths (λ) ranged from 180 to 1100 nm with 15–20% of the light in the UV region. Energy calculations were carried out according to the calibration of the equipment with a standard light source estimated by photodiode readings and following manufacturer's directions. Furthermore, transparency of the polypropylene film in the UV region was found to be above a 97% of the total emitted energy. Reduction of light transmission was negligible for visible wavelengths and increased for shorter wavelengths. However, only a 15% of the incident energy corresponding to wavelengths between 200 and 320 nm was blocked by the packaging material. Furthermore, spectroscopic measurements of the film-forming solution were carried out to optically characterize the gellan gum coating. The transmittance of the coating was calculated considering a film thickness of 155.75 mm, as reported in previous studies (Rojas-Graü, Tapia, Rodríguez, Carmona, & Martín-Belloso, 2007).

Temperature increase during the treatments was prevented by coupling a lab vacuum air extractor device to the treatment chamber. Temperature was measured with a thermocouple attached to the package surface and never exceeded 30 °C. Measurements were also taken at the surface of unpackaged fruit prices over the PL treatment to guarantee that abusive temperatures were not reached. Untreated coated apple cubes and PL-treated uncoated apple cubes were used as reference treatments. Immediately after processing, the samples were stored at 4 °C in the absence of light. Analyses were carried out periodically through 14 days for randomly sampled pairs of trays.

2.5. Microbiological analysis

Mesophilic aerobic, psychrophilic and yeast and mold counts on fresh-cut apples subjected to the different treatments were evaluated throughout storage. A portion of 10 g of apple, obtained from eight different apple pieces, was aseptically removed from each tray and transferred into sterile plastic bags. Samples were diluted with 90 mL of saline peptone water (0.1 g peptone/100 mL water,