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Development and evaluation of biodegradable films and coatings obtained from fruit and vegetable residues applied to fresh-cut carrot (*Daucus carota* L.)

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ABSTRACT

This work aimed to develop biodegradable coatings and films by using different extraction methods from fruit and vegetable residues. The effect of two coating strategies (immersion and spraying) and packaging methods on weight loss, color and microbial quality of minimally fresh-cut carrots (sliced and shredded) was investigated. Mechanical properties of the films were measured. The film obtained using a pH 7.0 buffer was applied to carrots as it had enhanced mechanical properties such as tensile strength and elongation at break (0.14 MPa and 17%, respectively). Microbial growth on coated carrots was similar to that of the control. Samples packaged with film had 27% weight loss less than the control samples. Immersion and spray coated shredded carrots had 12 and 25% less mass loss than the control, respectively, while for sliced carrots the difference was not significant. The whiteness index of film-packaged samples and immersion coated shredded carrots did not change appreciably. Despite the observed drop in color saturation expressed by chroma values, the color index was positive for all samples, indicating that orange color did not change during storage. The cutting method had a greater impact on the total color change than the coating treatment. In general, coated sliced carrots had a more prominent color change coated shredded ones. The data demonstrate the potential of a multicomposite vegetable matrix for producing coatings and packaging materials. Additional efforts are necessary to evaluate and optimize this process.

1. Introduction

Demand for fresh-cut vegetables has been increasing in recent years, generally because consumers look for freshness and convenience when they purchase these products. These commodities are perceived by consumers to be nutritious, convenient, and efficient in terms of meal preparation (ready-to-eat). Minimally processed carrots by peeling and cutting represent one of the major minimally processed vegetable products used as ready-to-eat foods or salad vegetables. However, they have a short shelf life, which is mainly attributed to mechanical stresses as well physiological disorders and decays (Lucera et al., 2010). Furthermore, the minimally processed carrots lose the bright orange appearance as a result of the whitish aspect on the surface due to dehydration and lignification, which limits consumers' acceptability and purchase intention (Lai et al., 2013).

New approaches to storage techniques including the development of edible coatings or film packaging have shown great potential and have attracted attention from many researchers in the field (Azarakhsha et al., 2014; Galus and Lenart, 2013; Maran et al., 2013; Azeredo et al., 2012; Ooi et al., 2012). Edible coatings and films may contribute to extend the shelf life of fresh-cut vegetables by reducing moisture and solute migration, gas exchange, respiration, and oxidative reaction rates, as well as by reducing or even suppressing metabolic disorders (Cortez-Vega et al., 2014; Pascall and Lin, 2013; Falguera et al., 2011). One major advantage of using edible films and coatings is that several active ingredients can be incorporated into the polymer matrix and

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consumed with the food, thus enhancing functional attributes. It is therefore necessary to take into account the variability of the chemical formulations of coatings and their variable activity in foods due to interactions with food components (Rojas-Grau et al., 2009).

Among the variety of compounds available for producing biodegradable films and coatings, fruit and vegetable solid residues present potential benefits, since they are produced on a large scale and their utilization converts vegetable waste into value added or functional products (Andrade, 2013; Ferreira et al., 2015a; Fahd et al., 2012). To date, few studies using fruit and vegetable residues, such as stems, stalks and seeds as an alternative source to prepare biodegradable packaging materials, have been reported in the literature (Barbosa et al., 2011; Ooi et al., 2012; Park and Zhao, 2006).

The aim of this study was: (a) to produce biodegradable coating solutions and films obtained from fruit and vegetable processing residues and (b) to evaluate the effectiveness of two different minimal processing treatments on carrot, combined with three distinct biodegradable coating strategies on the extension of shelf life, while maintaining the quality by means of weight loss, color measurements and microbiological analyses.

2. Materials and methods

2.1. Plant-based biodegradable residues

2.1.1. Fruit and vegetable residue flour

The biodegradable coatings and films were prepared using the fruit and vegetable residue (FVR) flour, obtained from the solid residue generated from the complete processing of fruits and vegetables, as previously published by Ferreira et al. (2015a). The FVR flour consisted of the following species: Selecta orange (*Citrus sinensis*), passion fruit (*Passiflora edulis*), watermelon (*Citrullus lanatus*), lettuce (*Lactuca sativa*), courgette (*Cucurbita pepo*), carrot (*Daucus carota*), spinach (*Spinacea oleracea*), mint (*Mentha* sp.), taro (*Colocasia esculenta*), cucumber (*Cucumis sativus*) and rocket (*Eruca sativa*). Fruits and vegetables were purchased from a local market, in Rio de Janeiro, Brazil.

2.1.2. Film-forming solution and biodegradable films

Formulation of film-forming solutions (FFS) were prepared by using 8 g of FVR per 0.1 L of different solutions as extractors: ammonium hydroxide and methaphosphoric acid at pH 7.0 and pH 9.0 and ammonium hydroxide and orthophosphoric acid at pH 9.0. This concentration of FVR flour was decided based upon the results of a preliminary study which evaluated various concentrations (Andrade, 2013). FFS were heated in a water bath (Dubnoff type, M. S. Mistura, Brazil) at constant agitation (200 rpm) for 45 min at 70 °C. After cooling at room temperature, FFS were obtained following the filtration through polyester cloth meshes and centrifugation (1500 × g, 10 min).

The film was produced from the FFS formulation by casting technique, by being dispersed in polystyrene plates (14.5 × 14.5 cm) and dried in a ventilated oven (Marconi, MA 035) at 50 °C for 6 h. The films were then removed manually from the plates and conditioned for five days in a chamber (Solab, Brazil) maintained at 25 °C and 57% relative humidity for subsequent characterization and application.

2.1.2.1. Characterization of the films. Film thickness was analyzed by averaging three random points using a digital micrometer (0–25 mm Digimess, Brazil). Mechanical properties of maximum tensile strength, elongation at break and the Young's modulus of the produced films were assayed using a texturometer (TMS/Pro, Food Technology Corporation, USA). Film probes with dimensions of 40 mm in length and 15 mm in width were used for assays. The initial grip separation and velocity were fixed, respectively, at 30 mm and 1 mm per s.

2.1.3. Edible coating solution

An edible coating solution (ECS) was prepared using essentially the same protocol as described above for FFS, with the exception that only aqueous solution was used for extraction.

2.2. Preparation of minimally processed carrots

Carrots (*D. carota*), at commercial maturity stage, were purchased from a local fruit and vegetable market in Rio de Janeiro, Brazil. Samples with mechanical injuries were discarded. The carrots were cooled for 24 h before processing, then immersed for 15 min in chlorinated water (sodium chloride 1 g per 0.1 L; sodium hypochlorite, 2.5 g per 0.1 L) and rinsed with tap water. The carrots were randomly distributed into two equal parts and two treatments were conducted in parallel with carrots from the same batch. The first treatment consisted of sliced carrots and the second was made up of shredded carrots. Carrots were manually peeled and cut into slices, or shredded using a vegetable processor (Cadence MPR853, Brazil). Fresh-cut carrots, either sliced or shredded, were treated in three different manners: two coating strategies (immersion and spraying) and packaging (covering with film).

2.2.1. Biodegradable film experiment

Among the various extractor solutions proposed for producing biodegradable films in this study, one was chosen based on its mechanical properties. The chosen film was produced, uniformly cut and manually applied to the processed carrots, while control samples were dipped in distilled water for 5 min. The film was removed from the carrot's surface just before performing the analyses.

2.2.2. Solution-immersion experiment

The carrots were completely submerged in coating solution for 5 min, while control samples were dipped in distilled water for the same period. Before storage, the coated carrots were suspended to drain the excess solution and to dry.

2.2.3. Spraying solution experiment

In experiments involving spraying, two compressor nebulizers (Omron NE-C801, China) were suitably connected and placed in a covered plastic box. Each carrot group was positioned between the

Table 1
Thickness and mechanical properties of different films produced using 8 g of FVR per 0.1 L of different solution extractors. Values are means ± standard deviations ($n = 3$).

Extractor	Thickness (mm)	Tension at break (MPa)	Elongation at break (E%)	Young's modulus (MPa)
Ammonium hydroxide and methaphosphoric acid at pH 7.0	0.19 ± 0.00^{ab}	0.13 ± 0.00^{b}	17.44 ± 1.74^{a}	0.07 ± 0.00^{b}
Ammonium hydroxide and methaphosphoric acid at pH 9.0	0.21 ± 0.00^{a}	0.01 ± 0.00^{c}	10.76 ± 2.52^{b}	0.03 ± 0.00^{c}
Ammonium hydroxide and orthophosphoric acid at pH 9.0	0.23 ± 0.00^{a}	0.25 ± 0.01^{a}	13.06 ± 2.27^{b}	0.18 ± 0.04^{a}
Distilled water	0.15 ± 0.03^{b}	–	–	–

Values within the same column with different letters are significantly different by Tukey test ($p < 0.05$).