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Effect of ferulic acid on the performance of soy protein isolate-based edible coatings applied to fresh-cut apples

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ABSTRACT

The economic importance of fresh-cut fruit market is becoming progressively more significant, while the food industry shows increased interest in innovation of products bringing health benefits.

The objective of this work was to assess the potential of incorporating ferulic acid (antioxidant with reported bioactivity that can act as cross-linking agent) in soy protein-based edible coating formulations in order to increase the quality and shelf life of fresh-cut apples (cv. *Golden*). Glycerol was used as plasticizer and ferulic acid was incorporated in concentrations between 1.0 and 4.0 g L^{-1}. The properties of fresh-cut apples were analysed during seven days of storage at 10 °C. A common commercial antioxidant (sodium ascorbate at 10 g L^{-1}) was tested for comparison. Uncoated apples and apples dipped into antioxidants solution were used as controls.

The results emphasized the need to incorporate this phenolic antioxidant in a biopolymer matrix, due to its hydrophobic characteristics and consequently a poor dispersion along the surface of the fruit. They also indicate that the efficiency of the coatings incorporating ferulic acid is highly dependent on pH. The formulation with ferulic acid at 4.0 g L^{-1} and pH 7.0 has demonstrated potential application in extending the shelf life of fresh-cut apples.

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1. Introduction

Associated with lifestyles of modern consumers, the economic importance of the fresh-cut fruit industry is becoming progressively more significant (Tapia et al., 2008). Consumers are aware of the importance of a healthy diet, and at the same time, they request easy-prepared foods from the industry (De'Nobili, Pérez, Navarro, Stortz, & Rojas, 2013). However, the commercial success of fresh-cut fruit has been limited due to their short life. When fruit are cut and peeled, their tissue responds with a steep rise in respiration rate, causing accelerated consumption of sugars, lipids and organic acids, and increasing ethylene production, which induces ripening and causes senescence (Kays, 1991, pp. 75–142). The shelf life and quality of cut fruit is further reduced by a series of decay processes also triggered by physical damage, including enzymatic browning, loss of texture, water loss, increased susceptibility to microbial spoilage, and production of undesirable odors and flavors (Olivas & Barbosa-Cánovas, 2005). The process analysis becomes even more complicate as each fruit has different quality attributes to be maintained during the storage period (Falguera, Quintero, Jiménez, Muñoz, & Ibarza, 2011) and each of them react differently to different treatments (Bico, Raposo, Morais, & Morais, 2010).

Strategies for shelf life extension of fresh-cut fruits include packaging and processing technologies. Among packaging technologies, modified atmospheres and the choice of suitable packaging materials have been widely adopted to slow down the produce metabolism (Del Nobile, Licciardello, Scrocco, Muratore, & Zappa, 2007). Various innovations are available today for limiting the quality loss, such as the use of ozone (Restuccia et al., 2014), non-thermal technologies (Moreira, Álvarez, Martín-Belloso, & Soliva-Fortuny, 2017) and edible coatings (Bonilla, Atarés, Vargas, & Chiralt, 2012). The application of edible coatings on fresh fruit and vegetables can reduce quality changes and quantity losses, through modification and control of the internal atmosphere of the individual fruit or vegetable (Dhall, 2013). Edible coatings are also useful as carriers for a broad range of food additives, including anti-browning agents, antioxidants, antimicrobials, colourants, flavors, nutrients and spices (Cerqueira et al., 2011; Falguera et al., 2011; Rojas-Graü, Oms-Oliu, Soliva-Fortuny, & Martín-Belloso, 2009;

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Wihodo & Moraru, 2013).

Therefore, several researchers have been studying the potential of various coating materials on increasing the quality and shelf life of fresh-cut fruit. Edible coatings can be prepared from proteins, polysaccharides, lipids or the combination of these components. Among them, protein-based edible coatings could be the most attractive, since protein films present impressive gas barrier and mechanical properties compared with those from lipids and polysaccharides (Azeredo & Waldron, 2016; Ou, Kwok, & Kang, 2004). Perez-Gago, Serra, and del Rio (2006) used a whey protein concentrate-based edible coating incorporating beeswax and ascorbic acid or cysteine to coat fresh-cut apples, with positive effect in the browning index but unable to control the weight loss.

Specifically, soy protein isolate (SPI) films have received a wide attention because of their low oxygen permeability, even when compared to the traditional low-density polyethylene film (Brandenburg, Weller, & Testin, 1993; Cuq, Gontard, & Guilbert, 1998; Ma et al., 2008), providing opportunities for preserving foods from oxidative deterioration. SPI is also an abundant and low-cost vegetable protein source, with nutritional quality and good biodegradability and biocompatibility (Cao, Fu, & He, 2007a; Sui, Jiang, & Yu, 2012; Wang, Marcone, Barbut, & Lim, 2012). Although several studies can be found in the literature concerning the properties and applications of SPI based edible films (Brandenburg et al., 1993; Choi, Kim, Hanna, Weller, & Kerr, 2003; Gennadios, Brandenburg, Weller, & Testin, 1993; Kang, Wang, Zhang, Li, & Zhang, 2016; Kim, Marx, Weller, & Hanna, 2003; Park, Rhee, Bae, & Hettiarachchy, 2001; Wang et al., 2012; Wihodo & Moraru, 2013; Zhang et al., 2010), few information can be found regarding the application of SPI edible coatings, namely in fresh-cut fruit. In a recent study (Marquez et al., 2017), reported reduced weight loss in fresh-cut apples coated with SPI or whey protein isolate. Ghidelli, Mateos, Rojas-Argudo, and Pérez-Gago (2015) also reported positive effects of a SPI-based coating formulation (incorporating beeswax) applied in combination with modified atmospheres to fresh-cut artichoke. In another study (Shon & Choi, 2011), the effectiveness of edible coatings containing SPI was demonstrated in reducing moisture loss of apples and potatoes in a five days period, particularly in combination with CMC, though final moisture loss for the best formulation was still over 20%. However, though the authors claim positive effects on oxidative discolouration, the colour study was terminated after 120 min due to excessive browning, which is clearly ineffective.

In spite of its low oxygen permeability, SPI films have been reported to be an ineffective moisture barrier (Gennadios et al., 1993; Ou, Wang, Tang, Huang, & Jackson, 2005; Park et al., 2001; Zink, Wyrobnik, Prinz, & Schmid, 2016), as expected for highly polar polymer films. Cross-linking using physical, chemical or enzymatic treatments has been explored by several researchers as a viable method to improve the mechanical strength and barrier properties of protein films (Azeredo & Waldron, 2016; Wihodo & Moraru, 2013). Chemical treatments include the use of cross-linking agents such as ferulic acid. Ferulic acid is one of the most abundant phenolic acids in plants, acting as a cross-linking agent in cell walls (Liyama, Lam, & Stone, 1984). Some recent studies have demonstrated that ferulic acid could act as satisfactory cross-linking agent in preparation of SPI, gelatin, starch-chitosan and sodium caseinate based edible films (Cao, Fu, & He, 2007b; Fabra, Hambleton, Talens, Debeaufort, & Chiralt, 2011; Mathew & Abraham, 2008; Ou et al., 2005). Other phenolic compounds have also been used as crosslinking agents in SPI films such as rutin, epicatechin, caffeic acid or gallic acid (Friesen, Chang, & Nickerson, 2015; Insaward, Duangmal, & Mahawanich, 2015). Ferulic acid can cross-link with proteins and polysaccharides by several mechanisms. In case of proteins, ferulic acid can oxidize to its quinone and then the quinone further react with amines on the protein, or it can cross-link with tyrosine and other amino acids through a free radical mechanism; a third possibility is its esterification with hydroxyl amino acids such as serine (Ou et al., 2005). Ou et al. (2005) demonstrated that an optimal concentration of ferulic acid incorporated in the SPI film increased the tensile strength, percent elongation at break and antioxidant activity of films for preservation of fresh lard.

Besides its low toxicity and cross-linking properties with both polysaccharides and proteins, ferulic acid has been also reported to have many physiological functions, including antioxidant, antimicrobial, anti-inflammatory, anti-thrombotic and anti-cancer activities (Ou & Kwok, 2004). It also protects against coronary disease, lowers cholesterol and increases sperm viability (Ou & Kwok, 2004). As emphasized in a recent paper (De'Nobili et al., 2013), the food industry shows an increased interest in product innovation which brings specific health benefit and the additives used in healthier food formulations should be as natural as possible.

The aim of this study was to assess the potential of the application of SPI based edible coatings, incorporating ferulic acid, in order to extend the shelf life of fresh-cut apples.

Though ferulic acid has been described as a good cross-linking agent for protein films, as described above, the incorporation of ferulic acid in SPI edible coatings applied to food was never studied, to our knowledge. Furthermore, the antioxidant and bioactive properties of ferulic acid can be an important feature for fresh-cut fruit applications. For this purpose, the weight loss and colour of cut apples, the two main quality indicator parameters chosen for this work, were evaluated during seven days, at 10 °C and 50% relative humidity (RH). For the selected formulations, apples were also analysed for firmness, pH and soluble solids content. Preliminarily, the water vapour permeability of films (WVP) with the same coating formulations was investigated. The effect of the application of SPI coatings, incorporating another antioxidant commonly used (namely, sodium ascorbate), on the quality of fresh-cut apples was also analysed, for comparison. Uncoated apples and apples dipped into solutions of the two antioxidants, under analysis, were used as controls.

2. Materials and methods

2.1. Materials

SPI (Ref. 20120201), with an isoelectric point of 4.6, and sodium ascorbate (Ref. 01010503) were kindly supplied by Formulab – Aditivos Alimentares, Ltd. Ferulic acid (Ref. 128708) were purchased from Sigma Aldrich Ltd and glycerol (Ref. 1.04092.1000) was purchased from Merck Ltd (E–301).

Apples (*Golden Delicious,* Portugal) were obtained from a local supermarket, between February and Abril 2013. Transport took about 10 min and they were immediately stored at 4 °C until processing. The average pH of the pulp of the apples was 4.5.

2.2. Methods

2.2.1. Preparation of film/coating formulations

The film/coating formulations were prepared with SPI at a concentration of 30 g L^{-1} and glycerol (Gly) was added, as plasticizer, to a final concentration of 9.0 g L^{-1} (corresponding to 30% w/w of polymer - SPI).

Sodium ascorbate (SA) was incorporated at a concentration of 10 g L^{-1} and ferulic acid (FA) was incorporated at four concentrations: 1.0, 2.0, 3.0 and 4.0 g L^{-1}.

Firstly, SPI solutions were prepared by dispersing the power in distilled water at room temperature for 1 h, followed by heating the

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