Industrial Crops and Products 83 (2016) 364–371

Contents lists available at ScienceDirect

Industrial Crops and Products

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

Effect of the natural surfactant *Yucca schidigera* extract on the properties of biodegradable emulsified films produced from soy protein isolate and coconut oil

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ARTICLE INFO

Article history:
Received 9 September 2015
Received in revised form 7 January 2016
Accepted 9 January 2016
Available online 25 January 2016

Keywords:
Biocomposite films
Protein
Casting
Lipid
Saponin

ABSTRACT

Protein films are known to have poor moisture barrier properties due to their hydrophilic nature, which can compromise the quality of packaged products. In this study, we present an alternative to overcome this problem by incorporating virgin coconut oil (VCO)—a hydrophobic component that presents good oxidative stability—into soy protein isolate (SPI) films. To emulsify the film-forming solution, the *Yucca schidigera* (YS) saponin was applied as natural surfactant. In order to understand the effect of VCO and YS into the SPI matrix, analyses of solubility, opacity, mechanical properties, water vapor permeability, morphological and structure properties were performed on the films. In general, all properties were influenced by the incorporation of VCO and/or surfactant, with exception of their solubility in water. Films containing VCO showed a plasticizing effect: increased flexibility and slight reduction in tensile strength. The water vapor permeability of the emulsion-based films was reduced in 35.4% when compared with the SPI film without VCO and YS. Morphological analyses indicated that the incorporation of VCO or Yucca extract caused notable changes in the structure of the SPI films, as also verified by Fourier transform infrared spectroscopy. Therefore, these data should help to better understand the role of lipids and surfactants in protein-based films for future industrial purposes.

1. Introduction

Increasing interest in reducing the environmental impact has encouraged the study and development of environmentally friendly and renewable alternative packages, such as edible and/or biodegradable polymer films and coatings originating from agricultural sources (Chang and Nickerson 2014; Santacruz et al., 2015; Kowalczyk et al., 2015). Among the biopolymers studied, soy protein stands as a remarkable film matrix due to its biodegradability and its structural and functional properties (Cho et al., 2007; Denavi et al., 2009; Atarés et al., 2010; Friesen et al., 2015; Hopkins et al., 2015), such as good gelling capacity and emulsifying characteristics (Nishinari et al., 2014).

Soy protein isolate (SPI) comprises a mixture of proteins containing approximately 90% globulins, whose main fractions include 7S (β-conglycinin) and 11S (glycinin) globulins (Cho and Rhee, 2004; Ryan et al., 2008; Hu et al., 2013). The β-conglycinin is less stable to heat than glycinin, being denatured at approximately 69 °C and 85 °C, respectively (Keerati-U-Rai and Corredig 2010). The SPI matrix is formed by protein–protein interactions catalyzed by heat, where the main forces involved in these interactions are disulfide and hydrogen bonds and hydrophobic interactions. Thus, the application of heat is essential for the formation of these bonds, once it alters the three dimensional structure of the proteins and leads them to expose their sulfidric groups and hydrophobic side chains (Shih 1998; Qu et al., 2015).

In general, films made from SPI have low barrier to water vapor (Su et al., 2010; Pan et al., 2014; Hopkins et al., 2015), good barrier to oxygen (Rhim et al., 2006; Denavi et al., 2009; Cho et al., 2010), moderate mechanical properties and are transparent (Krochta and Miller, 1997; Cho et al., 2007). Other authors have reported the incorporation of a hydrophobic component in the matrix reduced the water permeation in protein-based films (Valenzuela et al., 2013; Bahram et al., 2014; Wang et al., 2014).

Virgin coconut oil (VCO) is a vegetable type of oil, with significant food and non-food uses (Gunstone, 2002), obtained by pressing

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http://dx.doi.org/10.1016/j.indcrop.2016.01.014
0926-6690/

Table 1
Thickness and solubility of soy protein isolate emulsion-based films incorporated with virgin coconut oil and *Yucca schidigera* extract.

Formulation[a]	YS:Gly (w:w)	VCO:SPI (w:w)	Thickness (μm)	Solubility (%)
SPI/3YS0.7VCO	3:10	0.7:10	70.4 ± 8.8	16.05 ± 0.65[bAB]
SPI/3YS0.4VCO	3:10	0.4:10	67.3 ± 3.4	14.43 ± 0.11[aA]
SPI/3YS0.1VCO	3:10	0.1:10	68.6 ± 2.9	19.17 ± 0.90[cCD]
SPI/2YS0.7VCO	2:10	0.7:10	63.0 ± 7.7	17.43 ± 0.29[aBCD]
SPI/2YS0.4VCO	2:10	0.4:10	71.2 ± 3.9	17.21 ± 0.34[aBC]
SPI/2YS0.1VCO	2:10	0.1:10	68.6 ± 6.7	17.92 ± 0.49[aBCD]
SPI/1YS0.7VCO	1:10	0.7:10	68.8 ± 3.4	17.39 ± 1.11[aBCD]
SPI/1YS0.4VCO	1:10	0.4:10	67.8 ± 6.0	18.23 ± 1.43[aBCD]
SPI/1YS0.1VCO	1:10	0.1:10	61.4 ± 5.3	19.81 ± 1.43[aD]
Control	0	0	63.5 ± 2,8	16.15 ± 0.57[AB]

YS: *Yucca schidigera* extract; VCO: virgin coconut oil.
Thickness and solubility are means ± standard deviation of each formulation ($n = 10$) and ($n = 3$), respectively. Means in the same column with different superscript letters are significantly different by Tukey's HSD test ($p < 0.05$): uppercase letters (comparison between all formulations); lowercase letters (comparison between fixed concentrations of YS).

[a] All formulations contain: Soy protein isolate (SPI): 6.5% of SPI (w/w); Glycerol (Gly): 2.5:10 (Gly:SPI) and 20% ethanol (w/w film forming solution).

of fresh ripe pulp (copra) coconut (*Cocos nucifera* L.) (APCC, 2015). Coconut oil shows an excellent oxidative stability since it is low in unsaturated fatty acids (90% of the fatty acids are saturated) (O'Brien, 2009). This oil is a rich source of medium-chain triglycerides, where lauric acid (C12:0) stands as the major fatty acid, ranging from 46.6% to 48% of the total (O'Brien, 2009; Marina et al., 2009). Studies report that the antioxidant activity of VCO is assigned to the presence of phenolic compounds in their structure (Marina et al., 2009; Binsi et al., 2013). A recent study reported that the incorporation of VCO improved the flexibility of soy protein isolate films (Carpiné et al., 2015) and also improved the water vapor barrier and elongation of chitosan films (Binsi et al., 2013). Due to these characteristics and properties, VCO appears to be a promising hydrophobic component to be used in the improvement of edible SPI films.

Lipids may be incorporated into protein films matrices through the formation of emulsions, where the lipid compound is dispersed uniformly in a hydrophilic solution with the aid of surfactants (Bravin et al., 2004; Andreuccetti et al., 2011; Kowalczyk and Baraniak, 2014). Surfactants are materials added in small quantities to a mixture of two immiscible liquids phases for the purpose of creating a colloidal suspension (emulsion). The surfactant molecules having tendency the aggregation into micelles and reduce the interfacial free energy of the system in which they are found (Myers, 2006; Hasenhuettl, 2008). Previous studies have shown that the *Yucca schidigera* (YS) extract, a natural surfactant, can be used in the fabrication of biodegradable films (Andreuccetti et al., 2010; Rodríguez-Castellanos et al., 2013), providing good mechanical resistance and low water vapor permeability to them. *Yucca schidigera* is a palm tree native to Mexico and the Southern part of California (Sucharzewska et al., 2003; Santacruz-Reyes and Chien, 2012). The plant contains steroidal saponins (Kowalczyk et al., 2011) and phenolic constituents, being the last considered a potential source of antioxidant principles (Piacente et al., 2004). Due to their amphiphilic character, saponins are natural detergents, acting as emulsifiers and allowing the formation of stable foams (Hostettmann and Marston, 1995). Their use in the food industry is permitted by the U.S Food and Drug Administration (in the U.S. under section 172.510: Natural flavoring substances and natural substances used in conjunction with flavors, FDA, 2014).

The aim of this study was to investigate the effect of incorporating VCO and YS as a natural surfactant agent in the properties of SPI (emulsion-based films) films using the casting technique. Emulsion-based films were characterized with respect to their water vapor permeability, mechanical (tensile strength and elongation at the break), morphological (scanning electron microscopy) and structural properties (Fourier transform infrared spectroscopy analyses).

2. Material and methods

2.1. Materials

Commercial soy protein isolate (SPI, >90% protein content, Bremil Food Products, Brazil), virgin coconut oil (VCO, Copra Food Industries, Brazil), liquid *Y. schidigera* extract (YS, steroidal saponins content of ~10%, as informed by the manufacturer, Beraca Sabará Químicos e Ingredientes, Brazil), anhydrous glycerol (Gly, ≥99.5% purity, Panreac, Spain), ethanol (96% vol. purity, Panreac, Spain) and distilled water

2.2. SPI emulsion-based films preparation

The films were prepared by the casting method, where a film-forming solution (FFS) is prepared, poured in supports and dried over controlled conditions. The SPI constituted the main component of the continuous matrix of the films and its concentration was fixed in 6.5% (w/w film forming solution). Glycerol was applied as plasticizer, based on SPI content, at 2.5:10 (Gly:SPI, mass basis). Ethanol (20% w/w film forming solution) and distilled water (completing 100% w/w film forming solution) were applied as solvent. Virgin coconut oil was incorporated in the emulsion-based edible films as the hydrophobic compound and *Y. schidigera* extract was applied as the surfactant. To better understand the effects produced by different concentrations of VCO and YS in the SPI film matrix, three different levels of surfactant (1:10, 2:10 and 3:10, YS:Gly) and three different levels of VCO (0.1:10, 0.4:10 and 0.7:10, VCO:SPI) were evaluated. Films with no addition of VCO and YS were also prepared for later comparison (Control Film).

For the FFS preparation, the SPI was solubilized in distilled water at room temperature (25 ± 3 °C), followed by pH adjustment (9.00 ± 0.05) using NaOH (5N) and magnetic stirring for 60 min. The YS was previously dissolved in distilled water at 25 °C. Glycerol, YS aqueous solution, VCO and ethanol were added into the SPI solution, followed by heating in a thermostatic bath (Ethik Technology) until these solution reached 70 ± 3 °C. At the end of this period, the FFS was homogenized at 13500 RPM for 1 min, followed by 20500 RPM for 2 min using a homogenizer (Polytron, PT 3100D), according to the methodology described by Rezvani et al. (2013). Fixed volumes of the FFS obtained was dispersed on acrylic plates (14 cm × 14 cm) and dried at room temperature (25 ± 3 °C) for 24 h. The volume of solution required to maintain a constant film thickness after the drying step varied according to the solids content of each formulation. Before the characterization analyses, the films were conditioned in desiccators at 25 ± 3 °C and 57 ± 3% relative humidity (RH) (controlled by a saturated $Mg(NO_3)_2$ solution) during 7 days.