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Soluble soybean polysaccharide: A new carbohydrate to make a biodegradable film for sustainable green packaging

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ABSTRACT

Biodegradable edible films based on soluble soybean polysaccharide (SSPS), a new film-forming material, and three levels of glycerol (20%, 30% and 40%, w/w) as plasticizer, were developed and evaluated in terms of physical, mechanical, barrier and optical properties as well as their microstructure. SSPS-based films with a concentration of 20% glycerol possessed the lowest water vapor permeability. Increasing the glycerol content increased ($P<0.05$) values for elongation at break, but decreased ($P<0.05$) tensile-strength values. It was found that plasticizer concentration significantly affected the films' glass-transition temperature; however, it had no significant effect on their melting point. Color measurement showed that increasing the glycerol concentration caused the b and L values to increase, while ΔE value decreased. These results were explained by the film's microstructure, which was analyzed by atomic force microscopy and scanning electron microscopy. The results indicated that SSPS could be a promising food-packaging material.

1. Introduction

Nowadays, millions of tons of plastics are produced annually all over the world, and their production and consumption continue to increase; this increase has created serious environmental problems due to the materials' inability to biodegrade (Debeaufort, Quezada-Gallo, & Voilley, 1998). In order to solve the problems generated by plastic waste, much research effort has been done to obtain an environmental friendly material. Most of the research is focused on substitution of petro-based plastics by biodegradable materials with similar properties and low cost. Significant effort to extend the shelf life and enhance food quality while reducing packaging waste has encouraged food and packaging industries to explore for new biobased packaging materials that can reduce waste-disposal problems. Biopolymers derived from natural resources, which have attracted a great deal of attention in recent years, are considered as potential substitutes for traditional nonbiodegradable plastic films owing to their low cost, easy availability from reproducible resources and biodegradability (Janjarasskul & Krochta, 2010). Edible, biodegradable films, by acting as barriers to control the transfer of moisture, oxygen, lipids and flavors, can prevent quality deterioration and increase the shelf life of food products (Gontard, Duchez, Cuq, & Guilbert, 1994).

Several studies have reported the use of polysaccharides from different sources to prepare films and coatings with different properties, and have indicated that these carbohydrates are promising materials (Averous & Boquillon, 2004; Ghanbarzadeh, Almasi, & Entezami, 2010; Mali, Sakanaka, Yamashita, & Grossmann, 2005). Polysaccharide-based films are relatively stiff, and have a strong hydrophilic character compared with synthetic packaging films. Therefore, to overcome these films' brittleness and increase their workability and flexibility, various plasticizers, usually polyols, have been widely used. Glycerol, one of the most studied and popular, is a hydrophilic plasticizer; when added at the correct level with respect to the biopolymer content, it can reduce intermolecular forces and increase the mobility of polymer chains, a process generally used to improve the mechanical properties of edible films (Sobral, Menegalli, Hubinger, & Roques, 2001; Sothornvit & Krochta, 2001). In recent decade, a novel polysaccharide – soluble soybean polysaccharide (SSPS) – has been extracted from cell-wall material of the cotyledon of soybeans. SSPS has a pectin-like structure composed of a galacturonan backbone of homogalacturonan (α-1,4-galacturonan) and rhamnogalacturonan (repeating units being comprised of α-1,2-rhamunose and α-1,4-galacturonic acid),

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branched by β-1,4-galactan and α-1,3- or α-1,5-arabinan chains (Maeda, 2000; Nakamura, Furuta, Maeda, Takao, & Nagamatsu, 2002). SSPS has been reported to provide health benefits to humans through lowering blood cholesterol, improving laxation and reducing the risk of diabetes (Shorey, Willis, Lo, & Steinke, 1985; Tsai, Vinik, Lasichak, & Lo, 1987). Apart from its nutritional value, it has various functions such as dispersion, stabilization, emulsification and adhesion (Asai et al., 1994). Previous study have found that SSPS can be used as a functional ingredient in fortified foods (Furuta & Maeda, 1999). The literature data and preliminary studies in our laboratory have shown that SSPS can produce films with good appearance and satisfactory mechanical properties: it appears to have excellent potential as a film-forming agent. However, to the best of the authors' knowledge, there is no specific study on the film characteristics of SSPS. In the recent years, a major emphasis has been placed on the search for new film-forming materials with different compositions and properties. This study aims to develop a novel edible film based on SSPS, with potential applications as an edible film and a biodegradable food-packaging material, and to examine in detail the physical, mechanical, thermal, barrier and microstructural properties of the resulting films as a function of varying concentrations of glycerol as plasticizer.

2. Materials and methods

2.1. Materials

Soluble soybean polysaccharide (abbreviated as SSPS) was supplied by Fuji Oil (Osaka, Japan). Magnesium nitrate and sodium chloride (used to equilibrate films at 50% RH and 75% RH, respectively) together with sorbitol and glycerol were purchased from Sigma Chemical Co (St. Louis, MO). All other reagents used were of analytical grade.

2.2. Preparation of films

The films were prepared according to the so-called casting technique. SSPS film-forming solutions (3%, w/v) were prepared by dissolving 3 g SSPS in 100 ml distilled water under magnetic stirring (500 rpm), followed by heating to 90 °C on a hot plate for 30 min. The solution was then mixed with plasticizer (50% w/w of the polysaccharide). Both glycerol and sorbitol were tested as possible plasticizers, but the former gave better results. Following the addition of glycerol, stirring was continued for a further 15 min at 82 °C. SSPS films were cast by pouring the mixture onto polystyrene Petri dishes (14 cm in diameter) placed on a leveled granite surface for approximately 18 h at room temperature and room relative humidity. Films without any plasticizers were also prepared for later comparison. The film solution was left for several minutes to naturally remove most of the air bubbles incorporated during stirring. Dried films were peeled off the casting surface and stored inside desiccators at 25 ± 1 °C and 53% RH until evaluation.

2.3. Determination of physical properties of films

2.3.1. Film thickness

Thickness of the films was measured using a manual digital micrometer (Mitutoyo No. 293-766, Tokyo, Japan) to the nearest 0.001 mm. Measurements were made in at least ten random locations for each film, and an average value was calculated. The average value was used in calculations for tensile properties and WVP tests.

2.3.2. Moisture content

The films' moisture content was determined by measuring the weight loss of films, upon drying in an oven at 110 °C until a constant weight was reached (dry sample weight). Three replications of each film treatment were used for calculating the moisture content.

2.3.3. Film solubility in water

Solubility of SSPS films in water was measured following the method of Shojaee-Aliabadi et al. (2013). Film samples were dried at 110 °C for 24 h in a laboratory oven and then weighted to determine initial solid content. Pre-weighed film samples (1 cm × 3 cm) were immersed under constant agitation in 50 ml of distilled water for 6 h at 25 °C. After that period, the remaining pieces of films were filtered and dried at 110 °C to constant weight (final dry weight). The water solubility (%) of the film was calculated according to the equation WS (%) = $((W_i - W_f)/W_i) \times 100$, where W_i is the initial weight of the film expressed as dry matter and W_f is the weight of the desiccated undissolved film.

2.3.4. Moisture uptake

Moisture uptake was measured by following the method of Ghanbarzadeh and Almasi (2011) instead of the classical technique (immersion in water), because SSPS is very sensitive to liquid water and can partially dissolve after long time exposure to water. Prior to testing all specimens were first conditioned using anhydrous $CaSO_4$ at 0% RH for 48 h. The film samples were cut to a square piece of 2.0 cm × 2.0 cm and accurately weighed to give the dried film (W_i). After weighing, they were conditioned at 25 °C in a desiccator containing K_2SO_4 saturated solution to ensure a relative humidity of 97%. The samples were removed from the desiccator after 48 h and weighed (W_1). The moisture uptake values of the samples were calculated using the following equation:

$$\%\,\text{moisture uptake} = \frac{(W_1 - W_i)}{W_i} \times 100 \quad (1)$$

where W_1 is the weight of the film sample after exposure to 97% RH for 48 h, and W_i is the initial weight of the sample. Each test consisted of triplicate measurements and expressed as the mean value.

2.4. Water vapor permeability

Standard method E96/E96M (ASTM, 2012a) was used to determine water vapor transmission rate, with a 75% RH gradient at 25 °C. Diffusion cells containing anhydrous calcium chloride desiccant (0% RH, assay cup) were sealed by the test film (0.00287 m^2 film area). To maintain a 75% RH gradient across the film, a sodium-chloride-saturated solution (75% RH) was used in the desiccators. The RH inside the cell was always lower than outside, and water vapor transport was determined from the weight gain of the diffusion cell at a steady state of transfer. Changes in the weight of the cell were recorded to the nearest 0.0001 g and plotted as a function of time. The slope of each line was calculated by linear regression ($r^2 > 0.99$), and the water vapor transmission rate was calculated from the slope of the straight line (g/s) divided by the test area (m^2). All values for water vapor transmission rate (WVTR) were corrected for air-gap distance between the calcium chloride and the film surface according to the equations of Gennadios, Weller, and Testin, 1993. After the permeation tests, the film thickness was measured, and water vapor permeability (WVP) (g Pa^{-1} s^{-1} m^{-1}) was calculated as:

$$\text{WVP} = \frac{\Delta m}{A\Delta t}\frac{X}{\Delta p} \quad (2)$$

where $\Delta m/\Delta t$ is the weight of moisture gain per unit of time (g/s), X is the average film thickness (mm), A is the area of the exposed film surface (m^2), and Δp is the water vapor pressure difference