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Comparative study on the properties of flour and starch films of plantain bananas (*Musa paradisiaca*)

Franciele Maria Pelissari [a], Margarita María Andrade-Mahecha [a], Paulo José do Amaral Sobral [b], Florencia Cecilia Menegalli [a,*]

[a] Department of Food Engineering, School of Food Engineering, University of Campinas, CEP 13083-862 Campinas, SP, Brazil
[b] Department of Food Engineering, School of Animal Science and Food Engineering, University of São Paulo, CEP 13635-900 Pirassununga, SP, Brazil

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ABSTRACT

Biodegradable films were prepared by using the flour and starch isolated from plantain bananas of the variety "Terra" (*Musa paradisiaca*). Since the non-starchy fraction present in the banana flour represents 29.4% (on dry basis) of its composition, we considered it would be interesting to compare the properties of the film elaborated from this natural blend with that of the film produced from the banana starch only. Both films were characterized on the basis of their mechanical, barrier, optical, structural, and thermal properties. The banana flour film was less mechanically resistant but more flexible than the banana starch film. Despite the differences in the microstructure of the flour and starch films, the former was slightly soluble in water, and its water vapor permeability was similar to that of the starch film. Regarding the optical properties, the flour film was yellowish, which can be attributed to its protein content and the presence of phenolic compounds. The starch film, on the other hand, was lighter and less opaque. The FTIR spectra revealed the presence of the amide I group related to proteins only in the case of the flour film. Both plantain banana films displayed a C-type X-ray pattern and one glass transition temperature each, which was higher for the starch film (46.4 °C) as compared to the flour film (30.2 °C). The presence of other components (protein, lipids, and fiber) in the flour film had important effects on its properties. In general, the banana flour and starch are very promising materials for the formulation of coatings and films.

1. Introduction

The increase in non-biodegradable waste material and the difficulty in recycling most of the available synthetic packaging have been pushing research toward the development of new biodegradable materials that are suitable for packaging (Davis & Song, 2006; Marsh & Bugusu, 2007).

Various natural biodegradable polymers such as proteins and polysaccharides have potential application in the production of environmentally-friendly packaging (Chandra & Rustgi, 1998; Krochta & De Mulder-Johnston, 1997). Among polysaccharides, starch is the most widely employed in the elaboration of films, due to its low cost and abundance in nature. Several studies have reported on the use of starch from different sources in the preparation of films and coatings with different properties. Such works have indicated that these carbohydrates are promising materials in this regard (Alves, Mali, Beléia, & Grossmann, 2007; Avérous, Fringant, & Moro, 2001; Mali, Grossmann, García, Martino, & Zaritzky, 2004; Müller, Yamashita, & Laurindo, 2008). However, few studies on the utilization of flour as raw material for the production of films have been conducted over the last decade. The interest in combining polysaccharides, proteins, lipids, and fibers lies on the advantages and disadvantages of these components (Baldwin, Nisperos-Carriedo, & Baker, 1995). The use of natural blends directly obtained from agricultural sources takes advantage of each component in the original system and appears to be a new source of material in the area of biodegradable films (Tapia-Blácido, Sobral, & Menegalli, 2005). Rayas, Hernandez, and Ng (1997) have prepared films from three types of wheat flours. More recently, Andrade-Mahecha, Tapia-Blácido, and Menegalli (2012) have employed the flour from achira, a perennial plant native to the Andes in South America. Also, Tapia-Blácido et al. (2005) and Colla, Sobral, and Menegalli (2006) have produced films using amaranth flour as raw material.

An interesting renewable source for the production of edible and biodegradable materials is the banana fruit (Romero-Bastida

* Corresponding author. Tel.: +55 19 3521 4039; fax: +55 19 3521 4027.
E-mail addresses: fpelissari@hotmail.com, fcm@fea.unicamp.br (F.C. Menegalli).

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et al., 2005). Originated from Southeast Asia, bananas (genus *Musa*) are extensively grown in tropical and subtropical regions, and this fruit is considered an important food crop (Zhang, Whistler, BeMiller, & Hamaker, 2005). Unripe bananas are a good source of starch (over 70% of the dry weight) for the preparation of films. This is because their native starch contains about 36.2% amylose (Espinosa-Solis, Jane, & Bello-Pérez, 2009), which is the starch component that is mainly responsible for the film-forming capacity of starches. Starches isolated from banana, okenia, and mango have been recently used for the production of edible films (Romero-Bastida et al., 2005). In another work, films prepared from the banana flour were developed; however, only the oxygen permeability and the mechanical properties of these films were evaluated (Sothornvit & Pitak, 2007).

A study on the properties of films obtained from natural blends and their comparison with the characteristics of films produced from a component of the same botanical source would provide relevant information about the type of interactions taking place in the polymer matrix. Because a comparative study on the features of flour and starch films made from the same variety of banana has not yet been conducted, the objective of the present study was to investigate the influence of protein, lipids, and fiber of the banana flour on the properties of the film produced from this raw material and compare the characteristics of this film with those of the banana starch film. To this end, the flour and starch were isolated from unripe bananas of the variety "Terra" (*Musa paradisiaca*), a type of plantain that has exceptionally high starch, amylose, and resistant starch contents and which has been little investigated. The obtained films were characterized with respect to their mechanical, barrier, optical, structural, and thermal properties.

2. Materials and methods

2.1. Materials

The raw materials were prepared from unripe plantain bananas of the variety "Terra" (*M. paradisiaca*), according to the methodology described by Pelissari, Andrade-Mahecha, Sobral, and Menegalli (2012). The fruit was obtained from the harvest that took place in March 2010 in the state of Espírito Santo, Brazil, and it was not subjected to any postharvest treatment. The produced banana flour and starch had a dry basis yield of 50.6 and 28.5%, respectively. All the chemicals employed in this work were reagent grade.

2.2. Film production

The films were produced by the casting method using the optimal process conditions that had been established for the banana flour film in a previous research work. The process consisted in drying a film-forming suspension (FFS) that had been applied onto a support. The procedure developed herein involved the homogenization of an aqueous solution of 4% (w/w, d.b.) banana flour or starch by means of mechanical stirring for 30 min, followed by heating to the process temperature (81 °C) under gentle stirring. Glycerol (19 g glycerol/100 g flour or starch) was added at this point, and the solution was maintained at this temperature for 15 min. Next, the FFS was sonicated for 10 min, and 70 g of the solution was poured onto acrylic plates (18 × 21 cm), for achievement of a constant thickness. The films were dried in a chamber with air circulation under controlled conditions of temperature (54 °C) and relative humidity (48%).

The films were conditioned in desiccators under 58% RH, at 25 °C, for 48 h before being characterized in terms of the moisture content, mechanical properties, and water vapor permeability.

2.3. Film characterization

2.3.1. Scanning electron microscopy (SEM)

The surface and cross-section of the films were analyzed by SEM for microstructure evaluation. The film samples were cut into small pieces (20 mm × 20 mm) and dehydrated in a desiccator with silica gel (~0% RH) for 3 weeks. After this period, the dried samples were fractured with the help of tweezers, and small fragments were obtained. Samples of these fragments were fixed on aluminum stubs by means of a double-sided tape and were then coated with a layer of gold (Sputter Coater POLARON, model SC7620), to improve conductivity. The coated samples were viewed under a scanning electron microscope (LEO, model LEO 440i, Cambridge, England) operating at an acceleration voltage of 15 kV.

2.3.2. Thickness and density

The thickness of the films was measured with the aid of a manual micrometer (Fowler, model FOW52-229-001, Pennsylvania, USA) with an accuracy of 0.0001 mm. The mean thickness of each film was determined from an average of 10 random measurements.

For determination of the density, samples of each film were cut into 20 × 20 mm squares, and the thickness of these films was measured (3 random measurements). The film samples were dried at 105 °C for 24 h and weighed, and the density was calculated as the ratio between the weight and volume (thickness × area) of the film. The density experiments were accomplished in triplicate, and the data are reported as mean values.

2.3.3. Moisture content

The moisture content of the films was analyzed gravimetrically, in triplicate, by drying the samples at 105 °C for 24 h.

2.3.4. Mechanical properties

The puncture properties were determined by using a texture analyzer (Stable Micro Systems, model TA.TXplus, Surrey, England), following the methodology described by Gontard, Duchez, Cuq, and Guilbert (1994). Samples were cut into discs with a diameter of 60 mm and fixed onto a capsule with a circular opening of 34 mm diameter. A cylindrical probe with a diameter of 3 mm was moved perpendicularly to the film surface at a constant speed of 1 mm/s, until the probe passed through the film (rupture point). The puncture force was obtained directly from the force × probe displacement curves using the Texture Exponent 32 software, and the puncture deformation was calculated with the aid of Equation (1):

$$D = \frac{\left(d^2 - l_0^2\right)^{1/2} - l_0}{l_0} \times 100, \quad (1)$$

where D is the puncture deformation (%), d is the distance penetrated by the probe (mm), and l_0 is the radius of the film surface (mm).

The tensile properties were determined according to the standard method D882-02 (ASTM, 2002). The samples were cut into 25 mm wide and 115 mm long strips by means of a scalpel and mounted between the tensile grips. The initial grip separation and the crosshead speed were set at 80 mm and 1.0 mm/s, respectively. The tensile strength (force/initial cross-sectional area) and the elongation at break were computed directly from the strength × elongation curves using the Texture Exponent 32 software, and Young's modulus was calculated as the slope of the initial linear portion of this curve.

Analyses of the mechanical properties were performed by taking an average of six determinations for each sample, and the results are presented as mean values.