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Development and characterization of unripe banana starch films incorporated with solid lipid microparticles containing ascorbic acid

Tanara Sartori*, Florencia Cecilia Menegalli

Department of Food Engineering, School of Food Engineering, University of Campinas, CEP 13083-862, Campinas, SP, Brazil

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ABSTRACT

Incorporation of additives into polysaccharide-based films has emerged as a new strategy to release additives in food under specific conditions. However, there are no reports on the microencapsulation of additives with a hydrophobic agent prior to their addition to the polymer, which could stabilize the active compound and control its release. Therefore, this work aimed to produce films consisting of starch isolated from plantain bananas of the variety "Terra" incorporated with lipid microparticles containing ascorbic acid. Films produced by casting were characterized with regard to moisture, density, mechanical properties, color and opacity, light transmittance, water solubility, water vapor permeability, water uptake, XRD, and antioxidant properties. As a result of the lipid fraction enveloping the particles present in the packaging material, films additivated with lipid microparticles containing ascorbic acid showed lower water vapor permeability and elongation as well as higher tensile strength as compared with a control film containing no additives. In addition, films incorporated with solid lipid microparticles containing ascorbic acid displayed lower light transmission than the control films and a commercial polyethylene film. The microparticles acted as protective agents of the ascorbic acid antioxidant activity during film production. The antioxidant activity remained as high as 84% after the drying process.

1. Introduction

The characteristics of food products, such as shelf life, quality, and preservation, depend on the packaging material, which will determine gas, humidity, lipid, and flavor diffusion into the product (Atarés, Perez-Masia, & Chiralt, 2011). In this sense, several researchers have aimed to obtain environmentally friendly packages that will preserve food quality for a long time (Barbosa-Pereira, Angulo, Lagarón, Paseiro-Losada, & Cruz, 2014; Bitencourt, Fávaro-Trindade, Sobral, & Carvalho, 2014; Ferreira, Nunes, Castro, Ferreira, & Coimbra, 2014; Gomes, Borrin, Cardoso, Souto, & De Pinho, 2013).

Edible films and coatings can originate from biopolymers like polysaccharides, protein, and lipids or from mixtures of these biopolymers, to afford continuous matrixes (Shojaee-Aliabadi et al., 2013). Among polysaccharides, starch has received special attention: it is abundant and renewable, and it exists in various forms depending on the origin of the raw material. Therefore, starch can give rise to a variety of films, which has made it the object of countless research works in the area of edible films and coatings (Andrade-Mahecha, 2012).

Bananas are food crops that play an important role in the economy and food security of many tropical and subtropical regions in the world. According to data released by FAO (2014), worldwide banana production was around 118 million ton/year in the years 2012 and 2013, with Brazil being the fourth largest world banana producer after India, China, and the Philippines. Losses during banana production are very high and can reach 40% of the total produce, mainly due to inadequate post-harvest handling. Processing of surplus fruit and of fruit that is unsuitable for fresh consumption could help to reduce these losses (Tadini & Ditchfield, 2006). Unripe bananas have high starch content, which decreases along ripening. Dried unripe banana pulp contains between 70 and 80% of starch in its composition. Starch consists of amylose and amylopectin, which differ in terms of structure and molecular weight. Amylose is a linear component with lower molecular weight than amylopectin, and it can form films. Unripe banana starch exhibits high amylose content as compared with starches from other sources such as potato, corn, and wheat (Espinosa-Solis, Jane, & Bello-Perez, 2009; Zamudio-Flores, Gutierrez-Meraz, &

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* Corresponding author. Rua Monteiro Lobato, 80, CEP 13083-862, Campinas, SP, Brazil.

E-mail address: tanarasartori@gmail.com (T. Sartori).

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Bello-Pérez, 2011).

In addition to presenting diffusion barrier properties (humidity, gas, and volatiles), films and coatings may effectively carry food additives, including antioxidants, vitamins, colorants, flavors, and antimicrobial agents, thereby enhancing the integrity of the food they contain (Farias, Fakhouri, Carvalho, & Ascheri, 2012). Active packaging is an innovative concept in food packaging and helps to meet the continuous changes in market trends and consumer demands for food quality.

Incorporation of food additives into food packaging can improve the functional properties of films and edible coatings, helping to preserve food like fresh-cut fruit (Bonilla, Talón, Atarés, Vargas, & Chiralt, 2013). Eça, Sartori, and Menegalli (2014) have reviewed literature works on films and edible coatings containing antioxidants in different forms (extracts, essential oils, and pure compounds) and found that several researches about this theme are being developed. In addition to acting as protective barrier, active packaging increases the shelf life of the food materials onto which they are applied. For example, such packaging effectively reduces browning of fresh-cut fruits by increasing the antioxidant capacity of the coated or packed food.

As a food additive, ascorbic acid can serve as antioxidant, to protect the sensorial and nutritional properties of food. Its incorporation into films increases the functional properties of the packaging material. This has been demonstrated by recent research into the development of active films and coatings containing ascorbic acid as antioxidant for food application (De'Nobili, Pérez, Navarro, Stortz, & Rojas, 2013; Kowalczyk, 2015; Pérez, Fissore, Gerschenson, Cameron, & Rojas, 2012; Tapia et al., 2008). Robles-Sánchez, Rojas-Graü, Odriozola-Serrano, González-Aguilar, and Martin-Belloso (2013) have developed an alginate-based edible coating as carrier of ascorbic acid and citric acid and evaluated the antioxidant activity of the edible coating in fresh-cut Kent mangoes. These authors verified that the alginate-based edible coating containing ascorbic acid not only contributed to color retention in fresh-cut mangos, but also improved their antioxidant potential.

However, ascorbic acid is highly unstable and reactive, and it undergoes rapid degradation by different mechanisms (Bastos, Araújo, & Leão, 2009). The food industry commonly uses microencapsulation to stabilize sensitive compounds and to promote controlled release of active ingredients. In turn, controlled release overcomes the issue of additive loss along food product processing and storage (Desai, Liu, & Park, 2006). Among the several microencapsulation techniques, the spray chilling method has received special attention for encapsulation of hydrophilic compounds that are sensitive to high temperature, such as ascorbic acid (Abbas, Da Wei, Hayat, & Xiaoming, 2012). In this technique, hydrophobic materials serve as carrier, and low process temperatures are necessary to solidify the carrier and form the microparticles. In a previous work, we have studied microencapsulation of ascorbic acid by spray chilling using mixtures of fatty acids in different proportions as carrier; we observed that the microparticles presented high encapsulation efficiency and core release profile depending on the composition of the microparticles (Sartori, Consoli, Hubinger, & Menegalli, 2015).

In this context, this study aimed to produce and characterize unripe banana starch films added with solid lipid microparticles containing ascorbic acid with different release profile for subsequent application as edible coating in food materials, such as fresh-cut fruits. The hydrophobic encapsulating agent should provide an additional barrier to mass transfer besides allowing for the film itself to protect the active compound and enable its controlled release in food.

2. Material and methods

2.1. Material

Unripe banana starch, prepared from unripe plantain bananas of the variety "Terra" (*Musa paradisiaca*) according to the methodology described by Pelissari, Andrade-Mahecha, Sobral, and Menegalli (2012), was the raw material used to obtain edible films. The starch isolated from "Terra" bananas (*M. paradisiaca*) present the following composition on dry basis: 93.1% of starch, 25.6% of amylose, 3.6% of protein, 0.3% of lipids, and 0.4% of ash.

2.2. Solid lipid microparticles (SLM)

The SLM were obtained according to the procedure described by Sartori et al. (2015), by using mixtures of lauric acid (LA) and oleic acid (OA) at different ratios (70/30 and 80/20 g:g) as carriers. An aqueous ascorbic acid solution (30 g/100 g) was used as core material. The carrier and core material ratios employed in this work were 70/30 and 75/25 (g:g) (Table 1). Polyglycerol polyricinoleate (PGPR 90) at a concentration of 5 g/100 g of fatty acids was used as surfactant.

First, the fatty acids mixtures were heated to 10 °C above their melting points, which were 41.6 °C and 45.7 °C for the 70/30 and 80/20 LA/OA mixtures (g:g), respectively. After complete melting of the fatty acids mixture, the surfactant and aqueous ascorbic acid solution (core) were added at the desired proportions. Then, the mixtures were homogenized in an ultra-turrax (T 10 basic – Ika) operating at 30,000 rpm, for 5 min. The SLM were obtained on a Büchi-B290 spray dryer working in the spray-chilling module (Büchi, Uster, Switzerland). The emulsion was atomized with the aid of a double fluid pressurized atomizer equipped with a spray nozzle with a diameter of 0.7 mm. The sample feed flow rate was $5.28.10^{-4}$ m^3/h; the atomizing air and cooling air flows were maintained at 0.66 m^3/h and 35 m^3/h, respectively. The chamber inlet and output were cooled to 6.0 °C and 9.5 °C, respectively, by means of a Büchi B296 dehumidifier (Büchi, Uster, Suíça).

2.3. Film production

The banana starch films were produced by the casting method according to the methodology described by Pelissari, Andrade-Mahecha, Sobral, and Menegalli (2013), with some adaptations. An aqueous solution of 4% (g:g, dry basis) banana starch was homogenized by mechanical stirring for 30 min, followed by heating up to the process temperature (81 °C) under gentle stirring. Glycerol (22 g of glycerol/100 g of starch) was added at this point, and the solution was maintained at this temperature for 15 min. Next, the film-forming suspension (FFS) was cooled at 20 °C.

Simultaneously, 10 g of microparticles/100 g of starch were dispersed in 5 g of an aqueous Tween 80 (10%) solution. After FFS cooling, the dispersed particles were incorporated, and the mixture was homogenized in an Ultra-Turrax at 10,000 rpm, for 30 s. The FFS was allowed to stand under refrigeration overnight, to remove any bubbles formed during the homogenization process. After this period, 70 g of the FFS were poured onto acrylic plates (18 cm × 21 cm), and the films were dried in a chamber with air circulation under controlled temperature (25 °C) and relative humidity (50%) for 10 h. A film without added microparticles (control) and a film containing ascorbic acid at 0.9% (g:g of starch) in its commercial form (non-encapsulated ascorbic acid) were produced for comparison purposes. Before characterization, the films were conditioned in desiccators at 25 °C and 58% RH for 48 h.

The produced films were designated as follows: CF = control film without additives, CFA = control film containing non-