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Multi-objective optimization of process conditions in the manufacturing of banana (*Musa paradisiaca* L.) starch/natural rubber films

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Highlights

- Multi-objective optimization was used to evaluate films of starch and rubber.
- Restrictions in the quantity relations of starch/rubber.
- A structural characterization of the films was performed by X-ray, FTIR and SEM.
- The crystallinity, moisture and biodegradability properties were studied.

Abstract

Multi-objective optimization was used to evaluate the effect of adding banana (*Musa paradisiaca* L.) starch and natural rubber (*cis*-1,4-poliisopreno) at different ratios (1–13 w/w) to the manufacturing process of biodegradable films, specifically the effect on the biodegradability, crystallinity and moisture of the films. A structural characterization of the films was performed by X-ray diffraction, Fourier transform infrared spectroscopy and SEM, moisture and biodegradability properties were studied. The models obtained showed that degradability vs. moisture tend to be inversely proportional and crystallinity vs. degradability tend to be directly proportional. With respect to crystallinity vs. moisture behavior, it is observed that crystallinity remains constant when moisture values remain between 27 and 41%. Beyond this value there is an exponential increase in crystallinity. These results allow for predictions on the mechanical behavior that can occur in starch/rubber films.

Introduction

Currently, there is an environmental pollution problem generated in part by non-biodegradable synthetic polymers made from petroleum, most of which are very stable in nature with slow degradation. One solution to this problem is the use of biodegradable materials made from natural polymers such as proteins, chitin, cellulose, pectins and starch. Starch is a polysaccharide of plant origin in the form of granules of complex structure. It is found in cereals (corn, rice and wheat), tubers (potato, sweet potato and cassava), legumes (beans, peas and broad beans) and fruits (mango and banana). However, starch-based films have disadvantages such as high hydrophilicity (increasing water vapor permeability) and poor mechanical properties in comparison with common plastics (Bello-Pérez and Paredes-López, 1999, López et al., 2008; Hoover, Hughes, Chung, & Liu, 2010). Polymers such as natural rubber can be used for improving the physical and chemical characteristics of starch (Vieira, da Silva, dos Santos, & Beppu, 2011). Rubber is a hydrocarbon of high molecular weight called polyisoprene. Its monomer units are linked in long threadlike chains. It is produced by numerous plants (Mooibroek & Cornish, 2000), frequently found in specialized cells of plants which can be tapped in order to obtain their milky latex content. However, with starch/rubber-based films (bio-films) it is important to determine the suitable proportion of each component because in certain conditions they are immiscible to each other forming two layers and generating films with deficient characteristics of moisture, crystallinity and degradability in comparison with its homopolymers. There are examples of starch/rubber-based films made with starch sources such as sago (Afiq & Azura, 2013), cassava (Riyajan 2015) and corn (Jong 2016; Trovatti, Carvalho, & Gandini, 2015; Carvalho, Job, Alves, Curvelo, & Gandini, 2003) which served to improve their mechanical properties such as elasticity. The characteristics of moisture, crystallinity and degradability are coupled with one another; for example, high moisture facilitates the formation of film with low crystallinity and with degradation resistance; and low moisture hinders the formation of film with high crystallinity while causing easy degradation.

Multi-objective optimization can be a useful tool in overcoming the above-mentioned problem. In multi-objective optimization, all design objectives are important. Thus, all of them are optimized simultaneously. As a result, a set of solutions is provided (the so-called Pareto set), where all solutions are Pareto optimal. This means there is no solution that will worsen all design objectives; instead, a set of solutions with different trade-off between conflicting objectives is provided. Such techniques have been used successfully in many applications including biofeedstocks-to-biofuels system design (Eason & Cremaschi, 2014), the tuning of biological synthetic devices (Boada, Reynoso-Meza, Picó, & Vignoni, 2016), sugarcane biorefinery (Albarelli et al., 2015), thermal sterilization (Sendín, Alonso, & Banga, 2010), food distribution (Bortolini, Faccio, Ferrari, Gamberi, & Pilati, 2016), manufacturing of edible films (Ozdemir & Floros, 2008), modification of starch (Tijsen, Scherpenkate, Stamhuis, & Beenackers, 1999), food manufacturing (Wari & Zhu, 2016), and food packaging material (Turhan, Ayana, & Erdoğdu, 2007), among others.

The aim of this work is to perform a multi-objective optimization of degradability, moisture and crystallinity of starch/rubber films produced under different processing conditions and predict the physical behavior that can occur in the obtained films. The structure of this work is as follows: Section 2 presents a review of multi-objective optimization design procedures, Section 3 shows the materials (isolation of starch, starch/rubber film preparation, characterization of films) and methods (model identification, statement of optimization problem), the results are shown in Section 4, and finally the conclusion of this work is presented.

Section snippets