

BIOPOLYMERIC NANOMATERIALS

Fundamentals and Applications

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Applications in food products

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17.1 Introduction

Biopolymers can be classified in three categories, such as biopolymers isolated from biomass, biopolymers chemically synthesized using monomers from agro-resources, and biopolymers synthesized by means of microbial routes [1,2]. Particularly, most studies have been addressed to explore the applications of biopolymers isolated from biomass in the food sector because biomass is an abundant, renewable, and inexpensive raw material [2]. The most common biopolymers isolated from biomass are carbohydrates (e.g., cellulose, starch, and chitin/chitosan) and proteins (e.g., collagen/gelatin, gluten, soybean, zein, and whey) [2]. These biopolymers are “generally recognized as safe” and commonly used for food applications due to their natural sources, biocompatibility, nontoxicity, biodegradability, and acceptable mechanical properties [3]. More details about biopolymer classification and applications can be found in the specialized literature [2,4].

In the last years, several research studies have been focused on the development of biopolymer nanoparticles using carbohydrates and proteins as these materials have unique physical and chemical characteristics due to their quantum size, surface, and microquantum tunnel effects [5–7]. However, in the reviewed literature, no review paper has classified systematically the potential applications of nanoparticles based on biopolymers in the food industry. Therefore,

Physicochemical Properties of Potato Starch Nanoparticles Produced by Anti-Solvent Precipitation

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This work aims to understand the physicochemical properties of potato starch nanoparticles (SNPs) obtained by anti-solvent precipitation. Moisture content, water activity, color, morphology, thermal behavior (differential scanning calorimetry), swelling factor, solubility in water, water sorption isotherms, rheological properties, and stability in water are analyzed and compared using native potato starch (PS) as control. The resulting SNPs after anti-solvent precipitation have a particle size between 50 and 150 nm, smaller than those observed in PS (between 10 and 100 μm). SNPs behave as an amorphous material without gelatinization stage where the swelling factor is drastically reduced, while the solubility increased dramatically at low temperatures when compared with PS. The Guggenheim–Anderson–de Boer model from the isotherms data allows a calculation of the surface area, obtaining values of 105 and 211 $\text{m}^2 \text{g}^{-1}$ for PS and SNPs, respectively. The high surface area in SNPs is associated with an increase in the proportion of hydroxyl groups active for water adsorption throughout its structure. Both samples show Newtonian fluid behavior; however, SNPs solutions prove to be much more stable at room temperature than PS solution.

cooked, they can easily retrograde and induce syneresis.^[4] Chemical, physical, and enzymatic modifications of native starches are used to improve the physicochemical properties of these raw materials, reducing the starch instability in food systems.^[4,5]

A recent alternative used to alter the starch properties is to produce starch nanoparticles (SNPs) by anti-solvent precipitation. In this method, starch granules are hydrolyzed by heating this polysaccharide in the presence of an acid or alkaline solution, followed by the starch precipitation after the addition of ethanol drop wise to the first solution.^[6,7] Some researchers have explored the formation of SNPs by anti-solvent precipitation. In this way, Le Corre et al.^[7] and Qin et al.^[8] observed the production of modified starches with particle size between 30 and 100 nm, using waxy maize, normal maize, high amylose maize and corn, potato, tapioca, sweet potato, pea, and wheat starches, all prepared by anti-solvent precipitation.

Chacon et al.^[6] also observed the formation of a modified starch (SNPs) with particle size between 50 and 150 nm, using potato starch (PS). These authors observed that SNPs were most unstable to heating when compared with native PS. Finally, Chang et al.^[9] concluded that the particle size of modified starches can be modulated by the chain length of amylose into starch granule; hence, the particle size in starches was reduced from 206 to 103 nm as the amylose chains were hydrolyzed.

Other recent works have encapsulated essential oils, catechin, and quercetin using SNPs obtained by anti-solvent precipitation.^[10–12] These materials could be used as nanocarriers of active compounds with controlled release of active compounds in the intestine. However, in the reviewed literature, no research has studied the physicochemical properties of SNPs regarding food applications. Physicochemical properties such as moisture content, water activity, color, thermal behavior, swelling factor, solubility in water, water sorption isotherms, rheology, and stability in water of SNPs are necessary to propose new applications of this modified starch in the food sector.^[3,4] Hence, the objective of the present work is to study the physicochemical properties of SNPs obtained by anti-solvent precipitation.

1. Introduction

Starch granules are composed primarily of amylose and amylopectin in which amylose has a linear structure based on (1 $\rightarrow$ 4)-linked α -glucan units, while amylopectin has the same linear structure with many α -(1 $\rightarrow$ 6) branch points.^[1,2] Due to its gelling, thickener, and bulking properties, starch is widely used in food products such as soups, sauces, breads, snacks, batters, and meat among others.^[3,4] However, when native starches are

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Physicochemical Properties of Modified Starches Obtained by Anti-Solvent Precipitation Containing Anthocyanins from Jambolan (*Syzygium cumini*) Fruit

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This study aims to develop and characterize modified starch particles containing anthocyanins (ACNs) from jambolan (*Syzygium cumini*) fruit, produced by an anti-solvent precipitation method. Trapping efficiency, particle size distribution, surface charge, crystalline structure, chemical bonds, thermal properties, moisture content, water activity, color, and desorption experiments are carried out in modified cassava starch (MCS) and modified potato starch (MPS), both containing ACNs. Physicochemical properties of MCS and MPS both containing ACN (MCS-ACN and MPS-ACN) are compared using native cassava and potato starches, as well as modified cassava and potato starches without ACNs. ACNs are trapped into the modified starches and the trapping efficiency value oscillates between 9.89% and 12.37%. The resulting MCS-ACN and MPS-ACN powders display bimodal distributions with particle size lower than 900 nm and amorphous structure. Furthermore, the MCS-ACN and MPS-ACN powders show red color typical of ACNs and they are completely soluble in water and acidified water solutions at room temperature. This research reports for the first-time, information regarding the stabilization of ACNs using modified starch particles.

amylose/amylopectin ratio depends on the botanical source.^[1] Starch granules have semi-crystalline structure, being associated mainly to the amylopectin chain interactions. According to the literature, the starch crystallinity can be classified as A-, B-, and C-type, typical of cereal, tuber, and pulse starches, respectively. The A- and B-type are the most common crystalline structures found in native starches. Furthermore, the C-type is considered as a mixture of starches having A- and B-type crystalline structures. Each type of starch crystalline structure provides particular physical and chemical characteristics to the granules, desired or not by the industrial sector.^[6–9]

Normally, native starches have demonstrated poor solubility in cold water, easy retrogradation, low emulsification capacity, and inadequate storage stability at low temperatures.^[10] An alternative to improve the physicochemical properties of native starches is to modify them by means of chemical, physical, or enzymatic treatments.^[10–12]

The anti-solvent precipitation method is a chemical treatment where the starch granules are hydrolyzed by heating the biopolymer in the presence of an acid or alkaline solution, followed by the starch precipitation after the addition of ethanol dropwise to the first solution.^[13] Recently, this method has been used to retain and stabilize bioactive compounds such as curcumin, catechin, quercetin, and anthocyanins (ACNs) on the modified starches.^[14–18]

ACNs are phenolic compounds belonging to the flavonoids. These are the main group of natural hydrosoluble pigments in plants, responsible for blue to red coloration in many fruits and vegetables.^[19,20] The intake of ACNs is correlated with the prevention of cardiovascular diseases, cancer, and neurodegenerative disorders.^[21]

A fruit rich in ACNs is the jambolan (*S. cumini*), a tropical tree from the Myrtaceae family widely grown in Brazil as an ornamental and shade plant. Considering that the fruit has no commercial value in this country and most of the production is lost, jambolan becomes an inexpensive raw material for extraction of ACNs.^[22–24] This fruit exhibits an intense purple color due to the high content of ACNs (around 771 mg/100 g of dry weight) like 3,5-diglucosides of delphinidin, petunidin, and malvidin.^[25–27]

1. Introduction

Starches are polysaccharides used as energy source in various plants and they are stored in the form of grains with different shapes (e.g., spheres, ellipsoids, polygons, among others) and sizes (between 0.1 and 200 μm), depending of the botanical source.^[1] This polysaccharide can be classified as an abundant, inexpensive, biodegradable, and biocompatible biopolymer that has been widely used in different food and non-food applications.^[1–5]

Starch granules are conformed of linear amylose (20%–30%) and branched amylopectin (70%–80%) chains where the

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REVIEW ARTICLE

Progress in Biopolymer Coatings for Achieving Sustainable Paper and Paperboard Packaging for Food Applications: A Brief Review

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Keywords: cellulose | coatings | food packaging | shelf-life extension

ABSTRACT

Paper and paperboard are cellulosic materials used to manufacture food packaging. However, their low resistance to water and fat, as well as their poor barrier properties have limited their packaging applications as food contact materials. The current review analyses the use of biopolymeric coatings as an alternative to improve surface and barrier properties in paper and paperboard with focus in food sector application. Advances in coated paper (board) can be classified into three groups: (1) coatings manufactured with a single biopolymer; (2) coatings manufactured with composite biopolymers; and (3) biopolymeric coatings incorporated with bioactive molecules or nanoparticles. The use of a single or composite biopolymer coating improved the mechanical, barrier properties, and grease resistance. In contrast, the use of chemical compounds and nanoparticles has imparted active properties (antibacterial and ethylene scavengers) in the resulting coating paper (board). The water vapour transmission rate has been reduced with the use of biopolymeric coatings. Future studies should focus on applying coated paper (board) in foods with a special interest in food self-life, migration, and toxicity.

1 | Introduction

Paper and paperboard are materials based on cellulose whose difference is the grammage. While paper is an agglomerate of cellulose that forms a thin material (grammage $<250\text{ g/m}^2$), paperboard results from the aggregation of multiple layers to form thick materials (grammage $>250\text{ g/m}^2$) [1, 2].

Approximately 55% of cellulose is used to manufacture paper (board) materials for packaging applications [3]. In particular, paper (board) is widely used for food or consumer products because of its stable structure, attractive shelf display, effective printable surface, versatility, low cost and easy recycling [4]. Recently, this type of material has been appointed as a potential

candidate to replace synthetic plastic in packaging applications [5, 6].

Paper (board) has high porosity and hydrophilicity, making this material highly permeable to gasses (water vapour, oxygen, carbon dioxide and nitrogen), permeable to oils and extremely sensitive to water, thereby affecting its barrier and mechanical properties, and limiting its applications as food contact packaging [7, 8].

Paper (board) materials have an average biodegradation time of circa 6 months. These materials are normally coated with synthetic polymers to reduce the sensitivity of paper (board) to water and oil. Unfortunately, synthetic polymers are not biodegradable

RESEARCH ARTICLE

Active Films Based on Gelatin and Modified Curcumin: Physicochemical Properties and Food Packaging Application

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Keywords: antioxidant films | antisolvent precipitation | banana browning | nanocomposite films

ABSTRACT

This study investigated the development of active gelatin films containing modified curcumin and their application to reduce browning of banana peels. Curcumin, a natural antioxidant with limited water solubility, was modified through antisolvent precipitation, which obtained modified curcumin (MC) with increased water solubility and higher antioxidant activity. Gelatin films with different MC concentrations (0.0%, 0.1%, 0.3%, 0.5%, and 1%) were produced by the casting method. The resulting films were tested for thickness, morphology, crystallinity (XRD), chemical bonds (FTIR and Raman), water adsorption, water solubility, optical properties, wettability, water vapor permeation, mechanical properties, and antioxidant activity. Furthermore, the antioxidant film properties were evaluated using bananas as a food model. Structural analyses (XRD, FTIR, and Raman) confirmed that MC was well-incorporated without modifying the film's thickness, permeability, wettability, and mechanical properties. Scanning electron microscopy (SEM) showed a uniform distribution of MC, and the antioxidant activity (DPPH and ABTS assays) increased as a function of MC concentration. Gelatin films containing 1% MC reduced the browning of banana peels during the storage of this fruit at 25°C and 75% RH for 6 days. These findings highlight the potential of gelatin films containing MC as a sustainable bioactive packaging with promising food applications.

1 | Introduction

Packaging is important for the food processing, preservation, supply and distribution chain. Its main function is to contain and protect food material, but it is also essential to ensure food quality and safety, while also extending shelf life and minimizing food loss and waste [1, 2]. Traditionally, the industry has relied on synthetic polymers, such as polyethylene and polypropylene, due to their effectiveness in protecting food and extending its shelf life. However, growing concerns about environmental impact and sustainability have driven the search for more eco-friendly alternatives, leading to the development of biopolymeric packaging [3–6].

Aiming to reduce environmental problems, biopolymers, derived from renewable resources, have shown promise as substitutes for synthetic polymers, offering a more sustainable and biodegradable solution. Among various biopolymers, gelatin films have been applied to protect foods from drying and reduce food degradation by oxidation and light because this macromolecule can form effective barriers against moisture and gases. Gelatin films have the advantage of being naturally biodegradable and highly compatible with food matrices [1, 7–10].

In parallel, innovation in biopolymeric packaging has led to the enhancement of gelatin films through the incorporation of



Review

Flavonoids, anthocyanins, betalains, curcumin, and carotenoids: Sources, classification and enhanced stabilization by encapsulation and adsorption

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ABSTRACT

Bioactive compounds have remarkable biological activities for health, nutrition, and food preservation. However, these compounds are chemically unstable mainly when exposure at high temperatures, light, and humidity. Several stabilization techniques have been used to protect these compounds, expanding their application range. Therefore, this review aims to show the main bioactive compounds currently studied and the use of stabilization techniques, such as encapsulation and adsorption, for food application. A broader systematic classification of bioactive compounds based on phenolic and non-phenolic sub-levels was suggested, which can assist in a deeper discussion of results, including the correlation of biological activities, their synergistic effects, and their enhanced stabilization on materials that promote a well-controlled delivery (higher bioavailability). Research on Scopus Database was used to identify the scientific trends for stabilization methods (2016–2020). This review article focused on analyzing bioactive encapsulation using cold processing techniques such as ionic gelation, emulsification, complex coacervation, and adsorption to expand production and application in the food sector.

1. Introduction

The increase in lifestyle-related diseases has increased the demand for a well-balanced diet, including supplementation with bioactive compounds. These molecules are secondary metabolites found in algae, fruit, vegetables, and other edible plants that have proven efficacy in reducing risks of diseases such as diabetes, obesity, cancer, chronic leukemia, inflammation, and fighting free radicals (Dhingra & Bansal, 2014; Hayashi et al., 2012; Huang et al., 2019; Lee et al., 2020; Phan et al., 2018; Ribeiro et al., 2020; Upadhyaya et al., 2007).

Bioactive compounds are currently classified as phenolic compounds or non-phenolic compounds such as anthocyanins, carotenoids, curcumin, and betalains. Therefore, a broader systematic classification of bioactive compounds is essential to explore more profound their technological potential. These compounds have nutraceutical properties as antioxidant, antimicrobial, antifungal, anticancer, anti-inflammatory, anti-obesity, antidepressant activities. However, some of these compounds often (except betalains and anthocyanin) present low water solubility, and also, they are unstable in the presence of oxygen, light,

heat, and humidity (Segura Campos, 2018). In addition, the functionality of bioactive compounds is inherently related to their bioavailability, that is, they have to be effectively absorbed in the gut, then carried into the circulatory system, before reach the target cells. Moreover, they can be degraded due the pH change (stomach-small intestine) (Thakur et al., 2020).

In this sense, stabilization technologies such as encapsulation and adsorption could improve the stability and bioavailability of the bioactive compounds. The encapsulation can be coating and protect solid, liquid, or gaseous compounds (Assadpour & Jafari, 2018; Verma et al., 2020). In addition, adsorption also can be a useful alternative to preserve bioactive compounds. The adsorption occurs when an adsorbent (solid material on which adsorption occurs) comes into contact with an adsorptive (adsorbable substance in the fluid phase). In this process, atoms, molecules, or ions are retained on the solid surface by chemical or physical bonding (Kelly et al., 2019). For instance, the thermal stability of anthocyanins extracted from red chicory and then encapsulated in starch hydrogel beads has its antioxidant capacity improved ($\approx 55\%$), and its thermal stability was maintained even stored

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