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One-Pot Selective Functionalization of Polysaccharides with Urea

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Abstract: Natural Polysaccharides are polymers composed of monosaccharide units bound together by glycosidic linkages. In their native form, these polymers may not be able to provide all the desired properties for a particular application. Thus, the functionalization of its reactive hydroxyl groups would change their surface properties. In this work, we evaluated the derivatization of OH groups of maltodextrin polysaccharide with urea. By a one-pot selective procedure carried out at room temperature for 3 h, urea united at maltodextrin through covalent bonding was obtained. The results showed that after functionalization with urea, the pH and solubility in polar solvents of the new material increased. Derivatization of maltodextrin with urea confers stability, and terminal amide groups on the surface of this material represent a versatile reactive functional group for conjugation with other molecules for potential applications in the development of new materials.

Keywords: functionalization; maltodextrin; urea; one-pot synthesis

1. Introduction

Natural polysaccharides (NPLS) are the most important macromolecules in nature with functional diversity which can be considered as promising materials for numerous fields ranging from industrial to biomedical applications [1].

Amongst the biopolymers, natural polysaccharides are the most abundant and naturally available polymers which have gained a great popularity over the synthetic polymers because of their diverse functions. In addition, NPLS are documented as generally recognized as safe (GRAS) for targeting delivery because of their superior properties including non-toxicity and non-reactogenicity, easily available at large scale and relatively less expensive remarkable biocompatibility and extraordinarily biodegradability. They can be easily modified and processed according to the required designs and structures for further application in several areas [2].

Polysaccharides are carbohydrate polymers consisting of at least ten monosaccharides linked by glycosidic linkages, which are known as one of the crucial biomacromolecules in the growth and development of living organism [3]. NPLS are commonly functional macromolecular biopolymers isolated from several origins, including plants (i.e., cellulose, pectin), animals (e.g., chitosan, chondroitin), microbial (i.e., xanthan gum, pullulan, dextran) and algal (e.g., alginate) [2]. To improve the functions of polysaccharides obtained, physical, chemical and biological methods have been widely used to modify their structures.

It is known that the structural features of the polysaccharides, such as degree and steric configuration of substitutions, linkages of monosaccharides and substitutes, and molar mass and its distribution play a critical role on their physicochemical (e.g., solubility and fluid capability) and bioactive properties. Therefore, the modification of natively bioactive polysaccharides to extend their applications is of high importance. The aims of modification or functionalization include, but are not

limited to, the improvement and/or introduction of bioactivity, biocompatibility, control of biodegradability, as well as manufacturing and shaping for biomedical, pharmaceutical, and food applications [4].

Maltodextrin (MD) is a reducing hydrophilic polysaccharide that has been used extensively in food industry, beverage products and pharmaceutical industry (Figure 1) [5,6]. It Maltodextrins ($(C_6H_{10}O_5)_n$) are non-sweet saccharide polymers that consist of D-glucose units linked primarily by α (1,4)-glycosidic bonds and have a dextrose equivalent (DE) of less than 20 [7]. Typically, maltodextrins are obtained from starch polymers by acid hydrolysis, enzymatic hydrolysis, or a combination of both and are characterized by their dextrose equivalent, being the fraction of hydrolyzed glucoside bonds. Maltodextrins with different DE-values have different properties [8].

Maltodextrins and starches are some of the carbohydrates most commonly employed as vehicles for the microencapsulation of bioactive compounds [9]. Chemically, maltodextrin has different reaction sites in repeating glucose moieties providing wide alternatives in chemical conjugation process [5].

The functionalization of MD by incorporating reactive groups to the polymeric network, give these materials specific reactivity against different agents and introduce new properties or enhance properties already present. For that, in this work, a method of the functionalization of a matrix-based of maltodextrin with urea was developed. The procedure of functionalization gives active amide groups via a short spacer arm. Urea-maltodextrin matrix was synthesized and characterized by chemical techniques.

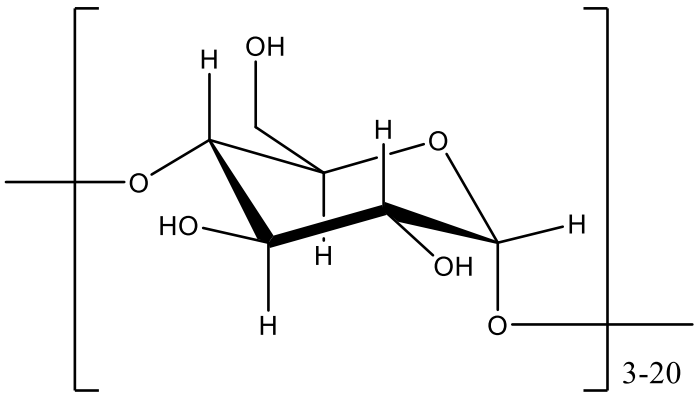

Figure 1. Maltodextrin structure.

2. Materials and Methods.

2.1. Materials

Solvents and reagents used during all the work were of analytical reagent grade and used without further purification. Maltodextrin was obtained from a commercial source (2.85 % of moisture).

2.1. Derivatization Procedure of Maltodextrin with Urea

The synthesis of maltodextrin-urea matrix was carried out by an epoxidation-coupling procedure [10]. In a typical experiment, maltodextrin (25 g) and urea (5 g) were dissolved in 60 mL of 2% NaOH aqueous solution under stirring at room temperature. After a few minutes, epichlorhydrin (25 mL) and sodium borohydride (0.03 g) were added to the solution. The solution was maintained at room temperature for 3–5 h. The product was washed with distilled water until a

negative test of urea. Finally, the solvent was evaporated, and the resulting suspension was centrifugated at 2500 RPM for 15 min. The material obtained after centrifugation was dried in an oven under reduced pressure.

2.1. Test of Urea

The assay was carried out by precipitation method which is based on the formation of urea nitrate with nitric acid [11]. Samples of wash water of the derivatization procedure (1 mL) were mixed with nitric acid (0.5 mL); as a result of the presence of urea, a white crystalline precipitate of urea nitrate is formed.

2.1. Characterization of the Maltodextrin-Urea Matrix

The maltodextrin-urea material was chemically characterized by FTIR and by solubility tests in different solvents. The presence of amine groups on the matrix was evaluated by a test of amines. For the test of amines, a mixture of about 0.05 g of material and 1 mL of water was heated until the liquid becomes turbid. Then of a few minutes, 1 mL of NaOH 10% solution and 1 mL of cupric sulfate 5% solution were added; the solution acquires a reddish-violet color verified the presence of amines group in the matrix.

The FTIR characterization was performed using the IRPrestige-21 (Shimadzu, Japan) with the KBr sample pellet method, using approximately 1% of the sample relative to the mass of KBr per pellet.

Solubility tests were performed by incorporation of 0.1 g of maltodextrin-urea at 10 mL of solvent. The solvents used were water, ethanol, 1-butanol, 2-propanol, ethyl acetate. Then of mixture the suspension at room temperature, the pH determination was carried out on pH meter.

At the same time, these characterization tests were evaluated with maltodextrin.

3. Results and Discussion

3.1. Functionalization of Maltodextrin with Urea

Maltodextrin is a saccharide mixture of polymers that consists of D-glucose units. It may be chemically modified to improve its physical and functional characteristics. MD has three hydroxyl groups in every monomeric unit, and they have good potential for derivatization with urea. The functionalization procedure comprises two steps: a) epoxy functionalization of maltodextrin, and b) coupling of urea to epoxy groups.

Preliminary experiments were carried out by evaluation of MD functionalization by two-steps: first the epoxidation of the maltodextrin matrix, and then the coupling of the urea. The epoxy groups were introduced by a known method based on the reaction of hydroxyl groups of maltodextrin with epichlorhydrin in the presence of sodium hydroxide and sodium borohydride [12]. Afterward, the reaction of epoxidated maltodextrin with urea was performed in an aqueous medium. The characterization of these materials shows the instability of epoxy groups.

To simplify the procedures and to obtain the best performance of the procedure, was carried out the epoxidation and the urea coupling steps together, i.e., a "one-pot" functionalization. The synthesis was evaluated during 3, 4, and 5 h of reaction. In the Figure 1 is shown the synthesis pathway of this procedure. The functionalization of maltodextrin added a three carbon atoms arm together with hydroxyl and amide groups.

3.2. Characterization of materials synthesized

In all experiences, the maltodextrin-urea materials obtained shown the same characteristics. These polymers showed a positive amine test and similar FTIR spectra.

From the FTIR spectra (not shown here) of maltodextrin and maltodextrin-urea, were identified the functional group present in the structure of these polymers. The FTIR spectrum of maltodextrin shown a characteristic absorption peak at 3431 cm^{-1} attributed to the presence of OH groups. Other

bands were observed at 2887, 1104 and 1356 cm^{-1} assigned to stretching vibrations of C-H and C-O bonds, and the symmetric vibrations of C-O-C bonds, respectively [13,14]. Compared with maltodextrin, the FTIR spectrum of maltodextrin-urea matrix shown distinctive absorption bands at around 1650, 1615, 1470 cm^{-1}, assigned to stretching vibrations of amide C–O bonds, to bending mode of amide NH bonds, and to symmetric stretching vibrations of C–N bonds. The presence of these bands indicated the formation of a C-NH-C=O bond on the maltodextrin-urea polymer [13,15].

On the other hand, the solubility of these materials was evaluated. Maltodextrin only was soluble in water. Maltodextrin-urea (M-D) polymer was soluble in water and ethyl acetate. When the alcoholic solutions of M-D polymer were added with 0.1% of water, they all showed total solubility. The pH of the aqueous solution of maltodextrin was 6.5, while in solutions of polymer M-D/solvents were 7.0–7.5. These results demonstrate that OH and amide groups present in the new polymer are of weak basicity and they are not completely dissociated at pH above 7.0–7.5.

4. Conclusions

In summary, a new maltodextrin-urea matrix was synthesized through a one-pot process. The physicochemical characterization of these materials confirmed the successful functionalization of hydroxide groups free of maltodextrin with urea. Derivatization of maltodextrin with urea confers stability, and terminal amide groups on the surface of this material represent a versatile reactive functional group for conjugation with other molecules for potential applications in the development of new materials.

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