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Production of cellulose nanocrystals from sugarcane bagasse fibers and pith

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ABSTRACT

Cellulose nanocrystals (CNs) were produced from unbleached and bleached sugarcane bagasse pulps by classical H_2SO_4 hydrolysis of fiber and pith fractions of pressed culms. Both the raw materials and final products were characterized by Fourier transform infrared spectroscopy, scanning electron microscopy, thermogravimetric analysis, field emission gun scanning electron microscopy, X-ray diffraction, and X-ray photoelectron spectroscopy. The advantages and disadvantages of using both unbleached and bleached pulps for the production of CNs were demonstrated and discussed.

1. Introduction

In recent decades, the growing recognition of the necessity to preserve the environment has resulted in an increased use of environmentally friendly materials and natural resources for various applications (Siqueira et al., 2011). Natural fibers may be used as important raw materials (Khalil et al., 2014), especially in developing countries with large agricultural production such as Brazil (Gañán et al., 2008).

Recent scientific and technological advances in the area of new materials have stressed the importance of using industrial and agricultural waste as a source of raw materials for production processes. In particular, reusing and recycling waste can minimize environmental problems related to its accumulation. In the context of sustainable development, lignocellulosic fibers have attracted much attention due to high availability and the demand for renewable sources for the production of polymers with good mechanical properties. The increased amount of research on cellulose nanostructures resulted in a significant increase in the number of related publications, which can be found in the Web of Science and Scopus databases. The lignocellulosic fibers can be divided into several groups based on their source and processing method. Considering industrial applications, special emphasis has been made on large quantities of produced agricultural residues or by-products (Siqueira et al., 2010). Among various agricultural crops, sugarcane plantations are famous for their production volumes and large amounts of residues. Brazil is currently the largest producer of sugarcane in the world, having manufactured about 632 million tons during the 2014/2015 season (mainly in the state of São Paulo). The use of the agricultural residues in biocomposites is one of the possible commercial applications that can unlock the potential of these underutilized renewable materials and create a non-food market for the agricultural industry (Alemdar and Sain, 2008). Thus, the lignocellulosic fibers can be perfect candidates for such new materials due to their compositions consisting of three main components with specific functions (cellulose, hemicelluloses, and lignin), which are combined in a composite tissue. In this work, cellulose is considered the most important component because of its special properties; it represents a linear polymer containing $(1 \rightarrow 4)$-linked β-glucopyranosyl residues. In nature, cellulose chains are packed in an ordered manner producing compact microfibrils, which are stabilized by both intermolecular and intramolecular H bonding (Fengel and Wegener, 1984). Up to 100 cellulose chains are grouped to form long thin elementary structures (fibrils) consisting of crystalline and amorphous parts. In this study, the crystalline parts with widths of about 5 nm (crystallites) were isolated by acid hydrolysis; however, their sizes may vary depending on the cellulose source. Because of their

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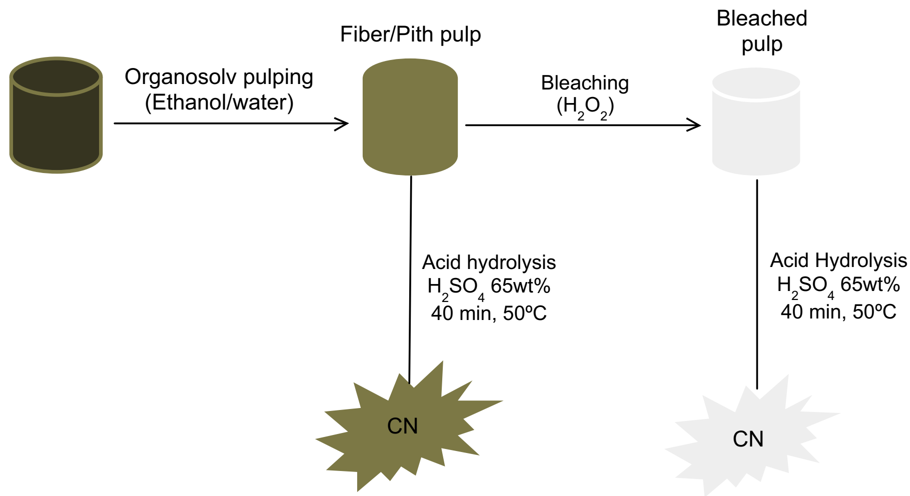

Fig. 1. A schematic representation of the preparation sequence for the nanocrystals obtained from the SCB fibers and pith.

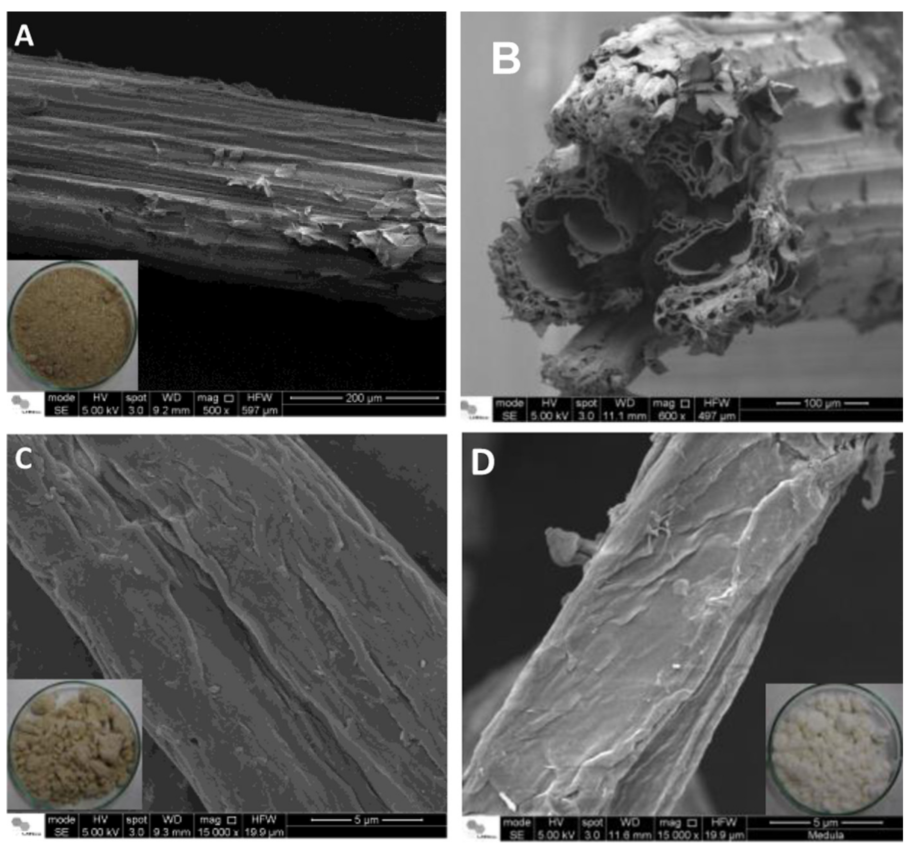

Fig. 2. SEM images of the a) untreated SCB fiber, b) transversal section of the fiber, c) fiber pulp, and d) bleached fiber pulp.

crystalline nature, these nanostructures are capable of enhancing the strength of plant stems. Various chemical and mechanical treatments of cellulose fibers change their surface characteristics and affect the properties of the resulting composites, which contain cellulose as a reinforcing agent. In recent years, sugarcane nanocellulose species have been manufactured by several research groups, (Teixeira et al., 2011; Mandal and Chakrabarty, 2011, 2014; Li et al., 2012; Slavutsky and Bertuzzi, 2014; Wang and Zhang, 2014; Ghaderi et al., 2014; El Miri et al., 2015; Zhang et al., 2016) in order to improve cellulose properties and widen its potential applications.

In general, the chemical route of nanocellulose extraction from lignocellulosic biomass contains the following steps: 1) a pulping process that opens the lignocellulosic structure, 2) a pretreatment procedure conducted to liberate cellulose by removing lignin or hemicellulose species; and 3) acid hydrolysis by a strong acid. Sugarcane bagasse (SCB) can be utilized as low-cost industrial feedstock since it may provide a sustainable and economic solution for the production of bio-based value-added products. However, in order to achieve significant yields, it is usually necessary to pretreat the lignocellulosic biomass before nanocrystal extraction and thus increase the related costs. Therefore, we investigated the effect of the cell type (fiber and pith) and lignin content (bleached and