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Nanocellulose in bio-based food packaging applications

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ABSTRACT

Cellulose nanostructures have been widely studied as components of materials for a variety of applications including food packaging. They are usually incorporated as a reinforcement phase in nanocomposites (as cellulose nanocrystals or cellulose nanofibrils). In other cases, cellulose nanostructures have been used as matrices for films—bacterial cellulose (BC) deserving a special attention in this context, since it is produced as naturally nanostructured membranes, which may grow in a medium containing other biopolymers (producing bottom-up built bionanocomposites), be impregnated with other components, or be disintegrated into nanofibribils or even nanocrystals. This review summarizes findings and prospective applications of nanocellulose for bio-based materials to be used in food packaging (including active packaging).

1. Introduction

Most materials used for food packaging applications are still produced from fossil fuels, thus non-renewable and also practically non-biodegradable, representing a serious environmental problem. Efforts have been made to reduce packaging waste while keeping food stability and quality, including development of bio-based materials from renewable sources. The global market for biodegradable polymers increased from 0.4 to 1.3 billion pounds between 2006 and 2013 (BCC Research, 2013). However, the use of bio-based materials for food packaging is still limited because of their usually poor physical properties. The incorporation of reinforcing structures such as nanocellulose to these materials may improve those properties.

Two main types of cellulose nanostructures may be obtained—cellulose nanocrystals (CNCs) and nanofibrils (CNFs). CNCs (or cellulose whiskers) are needlelike crystals measuring 4–25 nm in diameter and 100–1000 nm in length (Jonoobi et al., 2015), often produced by processes involving bleaching (especially for lignin-rich materials) and acid hydrolysis, which remove noncellulose and most amorphous cellulose leaving the crystalline regions (Xu et al., 2013). George et al. (2011) prepared BCNCs using cellulase as a cleaner and more ecofriendly method when compared to conventional acid hydrolysis; the enzyme-processed BCNCs presented improved thermal stability (degradation starting at 379 °C, against 184 °C for acid-hydrolyzed BCNCs). CNFs, also known as cellulose microfibrils, are aggregations of elementary fibrils (made up of crystalline and amorphous parts) with micrometer length and 10–100 nm in diameter (Jonoobi et al., 2015), usually isolated by mechanical processes such as high pressure homogenization, grinding and refining (Wang et al., 2007). An additional kind of nanocellulose reinforcing material is microcrystalline cellulose (MCC), closely related to CNC. It is formed by bundles of nanocrystals together with some amorphous parts, obtained by acid degradation which removes part of the amorphous regions (Petersson and Oksman, 2006).

Cellulose nanostructures have been most usually applied as reinforcing phases, but they may also be used as matrices for a variety of materials including films for food packaging applications. In this case, bacterial cellulose (BC) is especially useful, because of its peculiar properties. BC is already produced as a nanomaterial by *Gluconacetobacter* species cultivated in a medium with carbon and nitrogen sources. Although chemically identical to plant cellulose, BC is produced as a bottom-up process, in which the bacteria synthesize cellulose and build up bundles of nanofibrils forming and assembly of nanosized ribbon-shaped fibrils with 70–80 nm in width (Pecoraro et al., 2008) producing a pellicle (membrane) with a water holding capacity of 60–700 times its dry weight (Chang et al., 2012). It is also free from hemicellulose and lignin, reducing purifying costs and environmental damages derived from using harsh chemicals (Duarte et al., 2015). BC may be used to form films in different ways (Fig. 1). Intact BC membranes may be impregnated with dispersions containing other polymers

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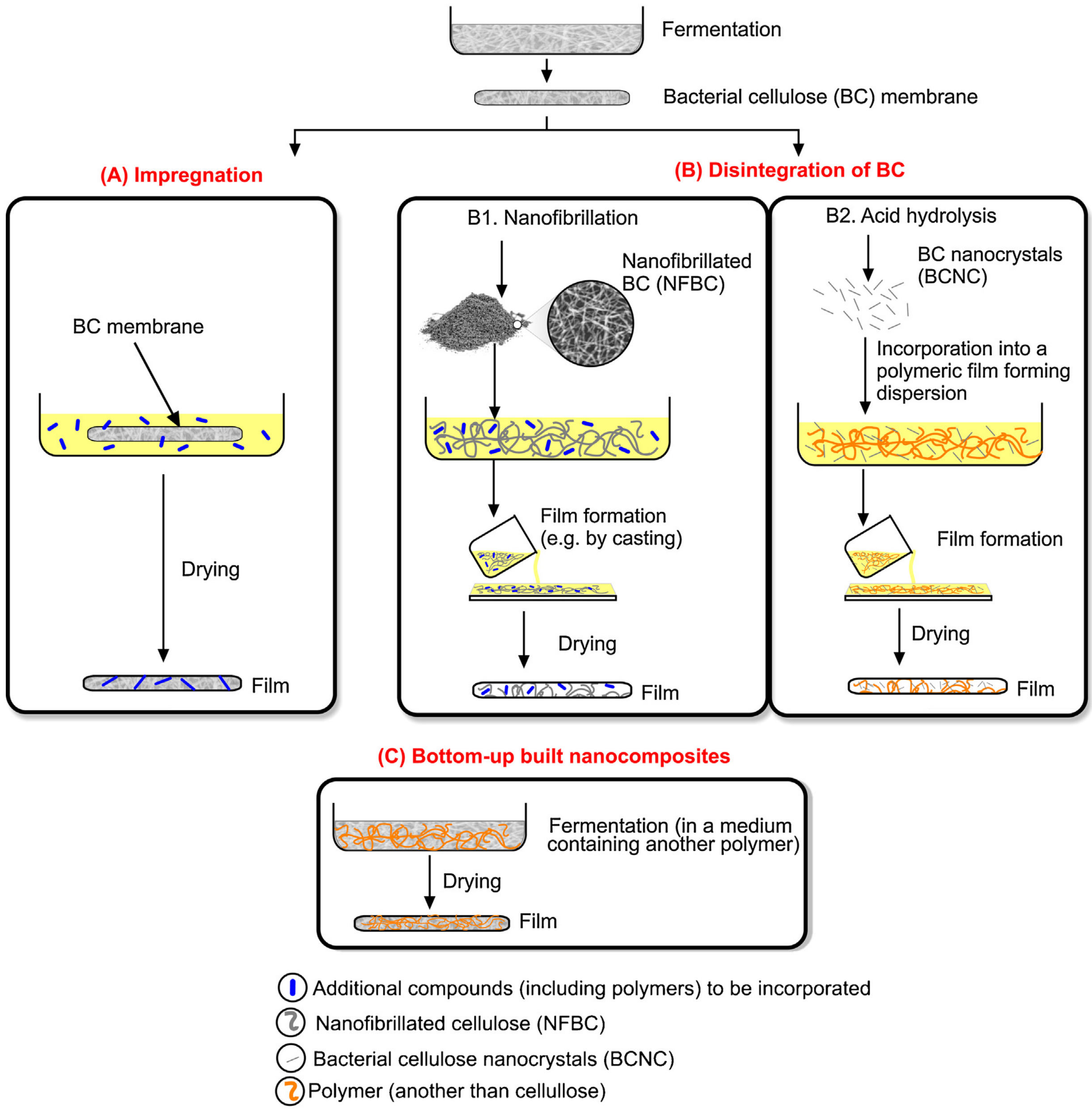

Fig. 1. Routes for use of bacterial cellulose for films: (A) impregnation with other film components; (B) physical and/or chemical disintegration of BC membranes to produce BCNF or BCNC; (C) addition of a second biopolymer to the culture medium for bottom-up built nanocomposites.

(Barud et al., 2011; Chang et al., 2012; Lin et al., 2013), reinforcing agents (Ul-Islam et al., 2012), and antimicrobials (Nguyen et al., 2008; Zhu et al., 2010). Also, a bottom-up technique may be used to self-assemble nanocomposites by growing BC in the presence of a second biopolymer added to the culture medium (Gea et al., 2010; Grande et al., 2009). However, a disadvantage in using intact BC sheets is the impossibility of changing their shape after fermentation, limiting applications such as coatings. Moreover, any changes in composition depend on either adding other components to the culture medium or impregnating membranes. For applications which require BC as a powder prior to formulation, sheets may be disintegrated by chemical and/or physical methods to produce bacterial cellulose nanofibrils (BCNF), or acid hydrolyzed to obtain bacterial cellulose nanocrystals (BCNCs) (George et al., 2011; George and Siddaramaiah, 2012).

Besides some basic requirements which are usually considered for most materials (e.g., tensile and thermal properties), food packaging materials should meet some specific requirements. The ultimate function of a food packaging is to extend food stability and to assure its quality/safety during shelf life. Barrier properties are especially important to reduce gases and water vapor exchanges between the food and the surrounding environment, decreasing the rates of chemical, physical, and microbiological changes. Water vapor permeability (WVP) and O_2 permeability (OP) are then important attributes for materials intended for food protection. A decreased water solubility of hydrophilic materials is also important, since a certain degree of water resistance is desirable for most food applications, especially to avoid film disintegration when in contact with humid food surfaces such as meat and fresh-cut fruits. Transparency is also usually desirable, so the consumer can see the product.

The objective of this review is to summarize findings and applications of cellulose nanostructures for bio-based food packaging