Bacterial cellulose for food applications
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ABSTRACT
Bacterial cellulose (BC), which is usually produced as pure membranes (sheets) by some bacteria, has been widely studied as a nanomaterial with unique properties for a variety of applications, but it has actually been used mostly for biomedical applications. There are many potential food applications that have not been adequately explored, nata de coco being virtually the only food product from BC on the market. Food applications have usually been considered as less economically feasible, but several studies had demonstrated the suitability of cost-effective fermentation media for producing BC, widening its scope of applications. BC may be used in foods as intact membranes impregnated with other components, or after disintegration or hydrolysis to produce bacterial cellulose nanofibrils (BCNF) or acid hydrolyzed to obtain bacterial cellulose nanofibrils (BCNF) and/or pectin (in different proportions) added with antimicrobial agents (monacolin K), extending the stability of the sausages when compared to the control.

Keywords: Bacterial cellulose, food applications, forms of presentation, and properties

Introduction
Bacterial cellulose production, forms of presentation, and properties

In 1886, Brown reported the production of cellulose by extracellular product by Acetobacter species. Nowadays, bacterial cellulose (BC) is well known as a nanostructured exopolysaccharide produced by some bacteria, especially from the genus Komagataeibacter (former Gluconacetobacter) in carbon- and nitrogen-containing media. When compared to plant cellulose, BC has the advantage of not requiring harsh chemical treatments for its isolation, since it is free from lignin and hemicelluloses. Moreover, it exhibits higher crystallinity, lower density, higher water holding capacity, and higher tensile strength due to its web-like network structure. BC is usually produced under static conditions as a membrane and could be the beneficiary of less processing and costs. Additionally, BC nanofibrils (BCNF), or acid hydrolyzed to obtain bacterial cellulose nanofibrils (BCNF) and/or pectin (in different proportions) added with antimicrobial agents (monacolin K), extending the stability of the sausages when compared to the control.

This article presents a brief overview of actual and potential applications of bacterial cellulose in food industry, based on the remarkable properties of such a unique natural nanomaterial.

Nata

The most traditional food use of BC is as the raw material for nata (or nata de coco), a traditional dessert from the Philippines that consists of cubes cut from BC sheets produced with coconut water or coconut milk, and immersed in a sugar syrup; similar products such as nata de polía (produced from pineapple juice) or nata de soya (from tofu whey) may also be prepared. Actually, any widely appreciated fruit juice could be tested for the development of novel nata products, adding regional appeal to the traditional Asian product. The Philippine production and exportation of nata has declined in the last few years. The highest volume (about 6300 ton) and value (about US$ 6.6 billion) of nata exportation by the country was recorded in 2011. The Philippines are still the main nata de coco producer, mainly by small scale producers; however, the country has faced problems, as described by Piazzo, including: (a) the high cost of the raw materials (especially coconut milk), which has been aggravated by a massive infestation of coconut trees by the coconut scale insect in some producing regions, (b) the adverse effects of extreme temperatures on the nata quality, and (c) competition from other coconut-producing neighbors countries, which have improved the process and the product quality.

Edible sheets or films

Our group has recently produced edible films from BCNF and/or pectin (in different proportions) added with mango or guava purées. Films with more BCNF than pectin tended to be stronger and with improved water resistance and water vapor barrier. The films could be applied as edible primary packaging, food wrappings, or even consumed by themselves as fruit sheets or ribbons, having a “fiber-rich” appeal. Alternatively, the sheets could have been prepared by imregnation of BC membranes into fruit juices or nectars.

When applied as edible packaging films, the materials could also include active compounds (such as antimicrobial or antioxidant agents) to help extend the shelf stability of the food to be packed. Some studies have reported effective antimicrobial actions of BC films containing food-grade antimicrobials such as nisin and lactoferrin. Antibacterial sausage casings have also been prepared from BC tubes impregnated with ε-polylysine, extending the stability of the sausages when compared to the control without ε-polylysine.

Fat replacer

BC has been used as a fat replacer in Chinese-style meatballs. When BC was added at 20% (completely replacing the added fat of the product), the cooking losses were higher than those of the control, and the texture was softer, which resulted in decreased acceptance. On the other hand, meatballs with 10% added BC presented similar sensory acceptance and stability when compared to the control.

A Surimi product prepared by using BC as a fat replacer presented increased gel strength and water-holding capacity due to its enhanced network structure. Moreover, being a dietary fiber, BC offers a number of health benefits. Chau et al. not only have demonstrated the hypolipidemic and hypcholesterolemic effects of BC in hamsters, but reported that its lipid- and cholesterol-lowering efficacy was significantly higher when compared to those of plant cellulose. Moreover, rats fed with meals

Figure 1 - Forms of applications of bacterial cellulose.
containing BC presented increased fecal weight and decreased transit time than rats from the control group.

Texture modifier
Because of its structural properties, BC may be used for several applications related to texture modification, including thickening and water binding.\(^\text{36}\) An ice cream containing BC was reported to retain its shape for 60 min at room temperature, because of the water binding properties of BC, while control ice cream (without BC) was completely melted after the same 60 min.\(^\text{36}\) Other texture-modification applications have been reported, such as gel strengthening for Tofu, preventer of cocoa precipitation in chocolate beverages, and stabilizer of beverage viscosity upon a heat treatment.\(^\text{39}\)

Pickering emulsion stabilizer
Pickering emulsions are those stabilized by solid colloid particles that adsorb onto the oil-water interfaces, forming a strong monolayer that avoids coalescence, even without the presence of surfactants.\(^\text{31}\) An amphiphilic character is typically required of the solid particles, although it is not mandatory.\(^\text{31}\) Advantages of Pickering emulsions (when compared to conventional emulsions stabilized by surfactants) include reduced foaming problems, lower toxicity, and reduced environmental impacts.\(^\text{31}\)

Cellulose is considered as amphiphilic, since it combines the hydrophilicity derived from the high surface density of hydroxyl groups and the hydrophobic interactions resulting from the crystalline organization and extensive hydrogen bonding of chains.\(^\text{31,32}\) Both BCNF and BCNC have been applied to stabilize surfactant-free Pickering emulsions.\(^\text{31,32}\) Actually, BC was more effective to stabilize oil in water (o/w) emulsions than commercial cellulose derivatives (HPMC and CMC), which was attributed to its strong fibril network adsorbed to the oil droplets.\(^\text{31,32}\) BCNCs (produced by sulfuric acid hydrolysis) were reported to perform better than BCNFs to stabilize o/w emulsions, which was ascribed both to their smaller size and to their higher (in absolute values) zeta potential derived from the sulfated groups.\(^\text{32}\)

Im mobilizer for probiotics and enzymes
Probiotic bacteria have been demonstrated to balance gut microflora and to provide consumers with health benefits. In the last decades, they have been used in several food applications. However, the survival of probiotics is usually impaired by processing and storage conditions, as well as by transit through the gastrointestinal tract.\(^\text{36}\) BC has been demonstrated to be a suitable cryoprotectant and immobilization support for probiotic bacteria,\(^\text{40}\) protecting the bacterial cells against gastric juices and thus favoring probiotic viability.\(^\text{36}\)

BC has been also suggested to immobilize enzymes such as laccase,\(^\text{40}\) which may be a useful approach to improve yield, quality and/or stability of foods.\(^\text{40}\)

Final considerations
Although bacterial cellulose is a GRAS polysaccharide material with unique properties such as water resistance and high water retention capacity, it has not yet been suitably explored for its potential food applications. Nata is basically a bacterial cellulose product at the food market, whereas a variety of other promising applications deserve to receive serious consideration.

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References