Chapter 5
Environmentally Sustainable Production of Bacterial Nanocellulose in Waste–Based Cell Culture Media and Applications

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ABSTRACT

Bacterial cellulose has attracted great attention due to the demand for eco–friendly materials and sustainable products. It possesses properties superior to those of plant cellulose and has potential uses in various applications. The wider application of bacterial cellulose depends on the practical considerations such as the scale–up capability and production costs. The high cost of bacterial cellulose production is the main drawback that hinders industrial implementation. The cost–competitiveness can be improved, and bacterial cellulose production can be maximized by the utilization of agricultural and industrial waste and by–products as bacterial cell culture media. This chapter provides an overview of cost–effective culture media for bacterial cellulose production by using agricultural waste as a primary nutrient source. The applications related to nanocellulose, and the future challenges are also described.

INTRODUCTION

A low-carbon society to reduce the emissions of greenhouse gases has become a worldwide trend to achieve climate protection goals. The greenhouse gases such as carbon dioxide are not only caused by the energy or fuel consumption in the industrial production and transportation, but also by plastics value chains (Bauer, Nielsen et al. 2022). Plastics have a large amount of carbon, which is released into the atmosphere at their end of life depending on polymer type and production technique. Therefore, recycling the plastics can keep the embedded carbon in the carbon loop (Bauer, Nielsen et al. 2022). On the other hands, producing plastics from biopolymer avoids adding more carbon footprint to the loop,

DOI: 10.4018/979-8-3693-0003-9.ch005

but maintain carbon neutrality to drive the carbon cycle (Schirmeister and Mülhaupt 2022). The use of bio-based alternatives to replace petroleum–based plastics is a key of the UN Sustainable Development Goals (SDGs) (Walker 2021). These sustainable alternatives can mitigate the single use plastics built up in the environment due to non-biodegradability and inadequate waste disposal (RameshKumar, Shaiju et al. 2020). Among different biopolymers, cellulose has been widely considered as good candidates to be applied in a variety of everyday applications for plastic replacement (Yun, Tao et al. 2023).

Cellulose, the most abundant biopolymer, has emerged as a multifunctional material widely used in the field of functional papers (Zhu, Zhu et al. 2015, Zhang, Zhang et al. 2018), packaging (Li, Wang et al. 2020, Tardy, Mattos et al. 2021), and other paper–based materials such as papers in flexible electronics (Guan, Song et al. 2020, Yang, Lu et al. 2021), and construction (Sandolo, Matricardi et al. 2009, Yang, Bai et al. 2018) due to its physical and mechanical properties. It is noteworthy, engineering with high industrialization and automation enables various cellulose–related products to be cost–efficient and available, thus demonstrating the high potential for plastic replacement (Liu, Du et al. 2021, Sun, Liu et al. 2021). Cellulose is a plant structural component bound to other biopolymers such as hemicellulose, lignin, and pectin (Brethauer, Shahab et al. 2020). These impurities are eliminated by acid/alkali pre-treatments and bleaching yielding the pure plant microcellulose. Nanocellulose from plants can also be obtained using a high-pressure homogenizer, grinders, and other mechanical processes whereby the high shear fibrillation process converts microcellulose into nanocellulose fibers (Abdul Khalil, Davoudpour et al. 2014).

Cellulose can also be synthesized by bacteria, so called bacterial cellulose, bacterial nanocellulose, or biocellulose (BC). A rod–shaped, aerobic gram–negative bacterium such as *Gluconacetobacter xylinus* is mainly used to produce a BC pellicle, a gelatinous cellulose sheet, with a denser surface on one side near the air and a looser layer on the other side (Jozala, Pértile et al. 2015). This biological process is more eco–friendly and does not use chemical treatment that generates wastewater effluent containing harmful chemicals like the process used for plant cellulose (Kongklieng, Kobayashi et al. 2023). Summative comparison between plant-derived nanocellulose and BC is shown in Figure 1. Because BC does not contain any hemicellulose, lignin, or other natural components, it is a high purity source of cellulose (Avcioglu 2022). The chemical structure of BC is identical to that of plant cellulose, but their physicochemical properties are different (Coseri 2021). One of the superior properties of BC over the plant cellulose is ultrafine nanoscale mat structure (Figure 2). This nanofibrous network structure of BC with high degree of polymerization (between 2000 and 6000) results in a high degree of crystallinity (> 70%), mechanical strength, water holding capacity, porosity (Keshk and Sameshima 2006, Mohite and Patil 2014), and high surface area (Ul-Islam, Khan et al. 2012). The properties of BC can be adjusted by choosing appropriate fermentation strategies, microbial strains, and modification (Raval, Raval et al. 2020).

The nanoporous network and the simple modification make BC a very attractive material for biotechnological applications (Avcioglu 2022). Modifications of BC by environmentally benign techniques have been developed, which fall into the categories of *in–situ* and *ex–situ* modifications to obtain the novel BC structure for each application (Taokaew, Phisalaphong et al. 2016). The *in–situ* modification is the addition of other materials to the culture medium before the biosynthesis (Taokaew, Seetabhawang et al. 2013). These exogenous materials are embedded in BC matrices resulting in new entanglements of nanofibrils (Taokaew, Phisalaphong et al. 2016). The addition of additives to the culture medium, such as ethanol (Park, Jung et al. 2003), agar (Bae, Sugano et al. 2004), sodium alginate (Zhou, Sun et al. 2007), not only have certain changes in BC crystallinity, mechanical strength, but also increase BC production. The *ex–situ* modification implies the modification of BC matrix after biosynthesis by