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Bacterial cellulose as a sustainable biomaterial: Production, functional properties and diverse applications

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Abstract
Bacterial cellulose (BC) has emerged as a promising sustainable biomaterial owing to its unique structural, physicochemical, and functional properties that distinguish it from plant-derived cellulose. Produced extracellularly by cellulose-synthesizing bacteria, particularly *Komagataeibacter* and *Acetobacter* species, BC exhibits exceptional purity, high crystallinity, superior mechanical strength, excellent water-holding capacity, biodegradability, biocompatibility and a three-dimensional nanofibrillar network. These characteristics have led to its increasing application in the food, biomedical, and industrial sectors. This review summarizes the structure, microbial sources, biosynthesis, and production strategies of bacterial cellulose, highlighting the influence of bacterial strain selection, genetic engineering, culture media, low-cost feedstocks, and bioreactor design on production efficiency and commercial feasibility. The use of agricultural and industrial waste substrates, along with optimized fermentation systems, offers a sustainable and cost-effective approach for enhancing BC production. The review also discusses the diverse applications of BC in the food industry, including fermented products such as nata de coco and nata de pina, dietary fibre, stabilizer, thickening agent, fat replacer, and biodegradable food packaging material with antimicrobial and antioxidant properties that improve food quality and shelf life. Furthermore, its biomedical applications in wound dressings, tissue engineering, vascular grafts, and regenerative medicine are highlighted due to its excellent biocompatibility and capacity for functional modification. Despite significant progress, challenges associated with large-scale production, process optimization, and cost-effective commercialization remain. Continued advances in microbial engineering, production technologies, and composite development are expected to enhance the commercial potential of bacterial cellulose as an eco-friendly, high-performance biomaterial for future food, healthcare, and industrial applications.

Keywords: Bacterial cellulose, biosynthesis, sustainable production, food and biomedical applications

Introduction

In recent decades, increasing attention has been directed toward the utilization of cellulose-based materials, leading to the rapid development of cellulose-based products. Cellulose is the most abundant biopolymer on Earth and is the major structural component of plant biomass. In addition to plants, cellulose is biosynthesized by certain bacterial species and is referred to as bacterial cellulose (BC) or microbial cellulose. Bacterial cellulose is an organic polymer with the molecular formula $(C_6H_{10}O_5)_n$, synthesized by several bacterial genera, principally *Acetobacter*, *Sarcina ventriculi*, and *Agrobacterium*. Brown [1] described bacterial cellulose as "the growth of an unbranched pellicle with a chemically equivalent structure to plant cellulose." However, BC possesses several distinctive properties that differentiate it from plant-derived cellulose, including high purity [2], a unique nanostructure [3], excellent mechanical strength, moldability during biosynthesis [4], high water-holding capacity, high crystallinity [5], and a high degree of polymerization [6]. These exceptional properties have led to the increasing use of bacterial cellulose fibrils in a wide range of industrial, biomedical, and food applications.

Structure

Bacterial cellulose is an unbranched polymer with nanofibrils, comprises of β-1→4 glucan chain with molecular formula $(C_6H_{10}O_5)n$. These glucan chains linked together via inter- and intra- hydrogen bonding. During formation of these fibers, polymerization and crystallization occur together that involves both characteristics. These nanofibrils having cross-sectional dimensions in the nm range aggregates to form microfibrils with a width of 50 -80 nm, and a thickness of 3-8 nm [7]. These can resultant to form a 3D network structure. This fine structure makes Bacterial Cellulose different from other microbial polysaccharides.

Microfibrills has been described as about 100 times smaller than plant cellulose [8, 9]. Previous studies revealed that the fibrous network of Bacterial Cellulose comprises of three dimensional nanofibres resultant in formation of hydrogel sheet with high surface area and porosity. *Acetobacter xylinum* produces cellulose I (ribbon-like polymer) and cellulose II (thermodynamically stable polymer) as described [8]. In the synthesis process, protofibrils of glucose chain secreted through bacteria cell wall, aggregate together forming nanofibrils cellulose ribbons [10]. These ribbons create the web shaped network structure of BC with highly porous matrix [11, 12]). Formation of cellulose with large number of hydroxyl groups describes it by means of hydrophilicity, biodegradability, and chemical-modifying capacity [13]. Later, mechanism of BC synthesis was clearly described [8]

Source

Bacteria that produce cellulose include Gram-negative bacteria species (*Acetobacter*, *Azotobacter*, *Rhizobium*, *Pseudomonas*, *Salmonella* and *Alcaligenes)*, and Gram-positive bacteria species (*Sarcina ventriculi)* [14]. Among the cellulose-producing bacteria, *A. xylinum*, *A. hansenii*, and *A. pasteurianus* are recognized as most efficient producers. Among these species, *A. xylinum* has been extensively used for basic and applied studies on cellulose owing to its ability

to yield relatively high levels of polymer from a wide range of carbon and nitrogen sources [15].

Production

To ensure favorable production yields and controlled costs, attention needs to be given to the species and genetic modification of the bacteria used, feedstock type, composition and the type of reactor for the production process [16].

Selection of Species

BC are often produced from the species such as Achromobacter, Alcaligenes, Aerobacter, Agrobacterium, Azotobacter, Gluconacetobacter, Pseudomonas, Rhizobium, Sarcina, Dickeya, and Rhodobacter [17]. It has been reported that Komagataeibacter genus (former Gluconacetobacter), major producer of BC owing to its capacity to metabolize a wide range of carbon/nitrogen sources extensively used for BC production [18, 19]. The development of genetic engineered strains is also a potential strategy that has been studied for enhancing BC production and yield as well as to improve its structural features [19]. In recent times, a strain of Komagataeibacter rhaeticus was isolated which grow in low-nitrogen conditions and produce cellulose at high yields. Its genome was sequenced, and a synthetic biology toolkit was developed for genetic engineering studies. This toolkit provided the characterization data essential for the engineering of K. rhaeticus iGEM, which enabled to design a system that permits tunable control over native cellulose production and to produce novel patterned and functionalized cellulose-based biomaterials [20] The development of genetically engineered strains also allowed the increase of BC production in a low oxygen environment, which can facilitate the use of static culture for production of BC. Recent advances in genetic engineering have enabled the development of bacterial strains with enhanced bacterial cellulose (BC) production under low-oxygen conditions, thereby improving the efficiency and feasibility of BC production in static culture systems [21].

Feedstock type

For BC production, Feedstock type plays vital role. Previous studies have been focused on identifying cheap feedstock that act as growth medium. For instance, using agricultural [22] and industrial wastes [23, 24]. Similarly, molasses [25], hydrolyzate of konjac powder [26], tea infusions [27] vinegar [28], fruit [29], fruit juices [30] and wheat straw acid hydrolysate [31].

Culture medium

The use of a glucose-rich culture medium, along with other necessary nutrient sources for the production of bacterial cellulose (BC), leads to elevated production costs, thereby restricting its potential applications. The Hestrin and Schramm (HS) medium, which comprises glucose, peptone, and yeast extract as sources of carbon and nitrogen, is a conventional culture medium employed for BC production [32] Furthermore, various alternative culture media have been explored for BC production, including fruit juices [33], sugar cane molasses [34, 35] and brewery waste [36] among others [37]. To enhance BC production, the incorporation of additives such as organic acids, carbohydrates, and ethanol into the growth medium has been documented [37]. Additionally, the strain Komagataeibacter medellinensis, when cultivated in a modified HS medium containing ethanol and acetic acid (both at 0.1 wt %), demonstrated a yield improvement of up to 279%. However, this modification resulted in a significant reduction in the crystallinity index (%), the degree of polymerization, and the maximum degradation temperatures [38].

The type of reactor for the production process

Production of BC has been investigated in static and in agitated conditions.

Static conditions

Static conditions are better for keeping a regular shape and to maintain good morphology. Using molds under static conditions, for example, can yield a product which is smooth and uniform, which is suitable for use in skin tissue repair and artificial blood vessels [4]. But this method does require more working space and workers, so making industrial scale production more expensive.

Agitated conditions

BC production under agitated conditions can form multi-shaped pulps, filaments and spheres. Compared with static culture, the agitated condition requires less space and work force, so reducing industrial production costs. Some of the traditional methods such as shake flasks, and stirred tanks have been used, but these agitated methods can induce mutations of the bacterial strain resulting in a significantly reduced BC synthesis [39].

By means of long culture period, intensive manpower, cellulose-negative mutants [40] both conditions are not feasible for large-scale production. Accordingly, reactors are designed in such a manner that minimize culture time and deter the conversion of bacterial cellulose-producing strains into cellulose-negative mutants. Thus, reactors are designed to lessen culture time and inhibit the conversion of bacterial cellulose-producing strains into cellulose-negative mutants. Reactors that are commonly used such as rotating disc reactor [39], the rotary biofilm contactor (RBC) [40], a bioreactor equipped with a spin filter [41] and a reactor with a silicone membrane [42].

According to expert's Rotary discs reactors attain 86.78% greater yield of cellulose rather than using traditional static fermentation, a yield of BC 6.17 g/L by using rotary biofilm contactor under the optimized culture conditions [43]. However, BC membrane production by means of an aerosol bioreactor had improved mechanical properties but lowered degree of polymerization (DP) than the usually produced cellulose. Nevertheless, it has not been possible to increase the BC yield to a satisfactory level. Accordingly, further improving the yield and lowering the cost for commercial mass production of BC is a challenging goal that entails further persistent hard work.

Applications

Due to its many unique properties, it has been used in the food industry, the medical field, commercial and industrial products, and other technical areas. Versatile structural material allows BC to be shaped in various ways to accommodate different uses.

Bacterial cellulose applications in food industry

Bacterial cellulose commonly used in the food industry by means of its high level of purity, change in color, change in flavor, and enormous potential to develop various shapes

and textures. Following are the uses of BC in food applications:

Nata de coco and Nata de pina

"Nata de coco" word derives from the Spanish meaning "cream of coconut" or "coconut milk-skin" [44]. It is a chewy, translucent, jelly-like food that is made with fermented coconut water [45]. It gels through the production of bacterial cellulose by Acetobacter xylinum [46]. In General, Nata produced by direct inoculation of Acetobacter xylinum into the fermentation medium. Cell immobilization technique helps to trap Acetobacter xylinum in beads for the fermentation of Nata de coco, constantly. Nata de coco originated in the Philippines is most commonly sweetened as a candy or dessert. It is an excellent ingredient for a variety of foods, including pickles, drinks, ice cream, puddings, and fruit cocktails [47].

On the other hand, Nata de pina ("pineapple gel") is a chewy, translucent, jelly-like food produced from fermented pineapple juice by adding Komagataeibacter xylinus [48]. Both flavors are controlled by the coconut water-based and pineapple water-based culture mediums, respectively [49, 50].

Dietary fiber

Bacterial cellulose is a form of such dietary fiber and regulatory is classified as "generally recognized as safe" (GRAS) [51] and was accepted as such by the USA Food and Drug Administration in 1992. Bacterial cellulose fibers are within the nano-scale with a fine three dimensional network structure that enables them to be used in novel food manufacturing processes [49].

Stabilizing agent

Usually Cellulose derivatives like CMC were employed in ice cream preparations as stabilizers by means of holding water, increasing the mix viscosity, reducing ice and lactose crystal growth on storage and giving resistance to melting [52]. On the other hand, Bacterial Cellulose encompasses a better emulsion stabilizing ability other than vegetable celluloses [53] that remains to be explored for ice creams.

Earlier study evaluated the effects of Bacterial Cellulose/soy protein isolate composites as a partial or total cream (fat) replacer on an ice cream model. In this study, the thermal stability, texture, rheological and emulsifying properties of Soy Protein Isolate were enhanced by the addition of bacterial cellulose. Also, the product having 20% Bacterial Cellulose/Soy Protein Isolate in the ratio 1:20 exhibits similar texture to the regular ice cream (with 30% cream), better melting resistance, moreover, additional advantage of lower calorific value [54].

Another study revealed that the shape of ice cream containing bacterial cellulose retained for at least 60 minutes after removal from freezer. On the other hand Control ice cream would melt away completely over the same period [55].

Thickening agent

BC showed possible future applications in the food industry especially processed foods through its thickening properties. The role of bacterial cellulose as an economical substitute thickener in o/w emulsions properties were investigated, moreover, correlated with expensive xanthan gum and locust bean gum [53]. While assessing their rheological profile, Bacterial cellulose showed similar shear thinning behavior as Xanthan gum. However, lesser quantity of Bacterial Cellulose was required to obtain the similar low shear viscosity (yield stress).

Furthermore, investigated the role of bacterial cellulose (BC) as a cheaper alternative thickener in o/w emulsions properties compared to xanthan gum (XG) and locust bean gum (LBG) which are highly priced [53]. To test the potential of BC to act as alternative thickener, emulsions stabilized with either BC, locust bean gum (LBG) and xanthan gum (XG) were compared. Their rheological profile showed that BC showed similar shear thinning behavior as XG, but smaller amounts of BC were needed to obtain the same low shear viscosity (yield stress). These results show that BC is a good alternative for commonly used thickeners that can be used in future applications in the food industry.

Fat Replacer

Consumers are becoming increasingly cognizant of the detrimental impacts associated with high-fat diets, leading to a rising demand for reduced-fat alternatives to the products they typically purchase. Consequently, there is a widespread necessity for novel food additives that are either fat-free or low in fat. Research on fat replacement has been conducted utilizing various hydrocolloids across a range of products, including cakes [56], emulsified meat products [57] and cheeses [58].

Bacterial Cellulose has been employed as a fat substitute in meatballs. The incorporation of 10% Bacterial Cellulose into meatballs resulted in sensory and shelf stability characteristics comparable to those of the control meatball. These meatballs exhibit juiciness and chewiness, positioning them as a viable alternative to fat in emulsified meat products [59].

The utilization of Bacterial Cellulose as a fat replacer in a surimi product led to enhancements in gel strength and water-holding capacity, attributed to its improved network structure. Given that the product maintains its original structure and demonstrates favorable mechanical properties, Bacterial Cellulose is now considered a suitable fat replacement within this food category [60]. Nevertheless, sensory evaluations have not been conducted to compare the acceptance of surimi containing Bacterial Cellulose with that of the conventional product.

Food packaging materials

Bacterial cellulose has a vast range of application from using as an edible food packaging material to antimicrobial food packaging [61, 62]. The purity, water holding capacity, direct modification, and moldability, biocompatible, biodegradable nature [63] and high water resistance performance [64] of BC biopolymer also makes it suitable as a substitute for manufacturing paper and paper products [62].

BC composites are used as antibacterial and antioxidant to prevent food contamination [65]. It has been reported that BC containing nisin used to control Listeria monocytogenes and total aerobic bacteria on the surface of vacuum-packaged frankfurters. Nisin-containing BC films were effective in controlling Listeria monocytogenes and reducing total aerobic plate counts on the surface of frankfurter sausages [66].

Composites of silver nanoparticles and bacterial cellulose prepared by in situ reduction of silver nitrate was able to extend the shelf life of tomatoes up to 30 days and can be applicable to extend shelf life for any kind of fleshy fruits

and vegetables. Altogether, bacterial cellulose impregnated with silver nanoparticles serves to be highly useful material for food packaging as well as healthcare systems [67].

Studies [68] evaluated the application of bacterial cellulose biofilm in fruits (strawberry cv. Festival and apples cv. Gala) minimally processed, kept by combine methods (biofilm and cooling), was efficient in maintaining the quality by physical and chemical stability of the products. Moreover, bacterial cellulose based film (polyvinylpyrrolidone + carboxymethyl cellulose + bacterial cellulose) can be an effective packaging material for both vegetables and meat products. Thus, it can be concluded that PVP-CMC-BC films can be promoted as an alternative packaging material for its better mechanical, optical and biodegradable properties [69].

Bacterial cellulose and eggshell composite membrane was preliminary tested on water and vegetable oil absorption ability. It was suggested that composite provided significant ability to adsorption of water and vegetable oil molecule. It exhibited the excellent performance and qualified as the excellent candidate for adsorbent material in food packaging [70]

Though elasticity and deformation are a prerequisite for selection of food packaging material, due to better tensile properties, transparent nature, printability 'PVP-CMC-BC' film is considered as the best and a novel green packaging material. It can be recommended for food packaging application which will be less expensive, recyclable/ biodegradable, sustainable and alternative to the conventional food packaging material [69].

Bacterial cellulose applications in medical industry

BC has been utilized in various domains, including wound dressing [71] and blood vessel regeneration [72]. Despite the distinctive characteristics of BC, certain limitations hinder its broader applications, such as the absence of antibacterial properties, optical transparency, and the ability to bear stress. To address these challenges, BC composites have been developed, comprising a matrix and reinforcement materials. BC features a porous arrangement of fibers, serving as a matrix that accommodates a range of particles from diverse reinforcement materials. The incorporated reinforcement materials enhance BC by contributing additional biological and physicochemical properties [73].

Conclusion

Bacterial cellulose has become a promising sustainable biomaterial due to its high purity, nano-fibrillar structure, biocompatibility, strong mechanical properties and their ability to break down naturally. These special characteristics have made it possible to use it in many areas such as food, medicines and industries. Advances in areas like microbial engineering, affordable materials, better fermentation methods and improved production processes has helped to increase efficiency and make large-scale manufacturing more feasible. However, concerns like high costs, difficulty in scaling up production and challenges in applying it in industry still hold back its wide use. Future studies should target to create cost-effective production methods and functional bacterial cellulose composites to speed up its use in sustainable food systems, healthcare and advanced biomaterials.

References

1. Brown AJ. An Acetic Ferment which forms Cellulose. Chem Society,1988:49:432-439.
2. Jonas R, Luiz F. Production and application of microbial cellulose. Poly Degrada and Stabi,1998:59(1-3):101-106.
3. Chen P, Cho SY, Jin HJ. Modification and Applications of Bacterial Celluloses in Polymer Science. Macromolecular Res,2010:18:309-320.
4. Klemm D, Schumann D, Udhardt U, Marsch S. Bacterial synthesized cellulose - artificial blood vessels for microsurgery. Progress Polymer Sci,2001:26(9):1561-1603.
5. Keshk SM. Bacterial Cellulose Production and Its Industrial Applications. Bioproces Biotechnique,2014:4(2).
6. Dahman Y, Jayasuriya KE, Kalis M. Potential of Biocellulose Nanofibers Production from Agricultural Renewable Resources: Preliminary Study. Appl Biochem and Biotech,2010:162(6):1647-1659.
7. Tabuchi M. Nanobiotech versus synthetic nanotech. Nature Biotech,2007:25(4):389-390.
8. Chawla PR, Bajaj IB, Survase SA, Singhal RS. Microbial Cellulose: Fermentative Production and Applications. Food Tech Biotech,2009:47(2):107-124.
9. Gayathry G, Gopalaswamy G. Production and Characterization of Microbial Cellulosic Fibre From *Acetobacter Xylinum*. Ind J Fibre Text Res,2014:39:93-96.
10. Ross P, Mayer R, Benziman M. Cellulose Biosynthesis and Function In Bacteria. Microbiol Rev,1991:55(1):35-58.
11. Dahman Y. Nanostructured Biomaterials and Biocomposites from Bacterial Cellulose Nanofibers. J Nanosci Nanotech,2009:9:5105-5122.
12. Maria LCS, Santos ALC, Oliveira PC, Valle ASS. Preparation and Antibacterial Activity of Silver Nanoparticles Impregnated in Bacterial Cellulose. Polímeros: Ciencia e Tecnologia,2010:20:72-77.
13. Klemm D, Heublein B, Fink HP, Bohn A. Cellulose: Fascinating Biopolymer and Sustainable Raw Material. Angewandte Chemie - International Edition,2005:44(22):3358-3393.
14. Shoda S. Recent advances in bacterial cellulose production, Biotechnology. Biotechnol Bioprocess Eng, Published online 2005:101-108.
15. Bielecki S, Krystynowicz A, Turkiewicz M, Kalinowska H. Polysaccharaides and Polyamides in the Food Industry. (Steinbuchel A, Rhee SK, eds). Wiley-VCH Verlag, 2005, 31-85.
16. Shi Z, Zhang Y, Phillips GO, Yang G. Utilization of bacterial cellulose in food. Food Hydrocol,2014:35:539-545.
17. Lin SP, Loira Calvar I, Catchmark JM, Liu JR, Demirci A, Cheng KC. Biosynthesis, production and applications of bacterial cellulose. Cellulose,2013:20(5):2191-2219. doi:10.1007/s10570-013-9994-3
18. Lee KY, Buldum G, Mantalaris A, Bismarck A. More than meets the eye in bacterial cellulose: biosynthesis, bioprocessing, and applications in advanced fiber composites. Macromol Biosci,2014:14(1):10-32. doi:10.1002/mabi.201300298

19. Islam MU, Ullah MW, Khan S, Shah N, Park JK. Strategies for cost-effective and enhanced production of bacterial cellulose. Int J Biol Macromol,2017:102:1166-1173. doi:10.1016/j.ijbiomac.2017.04.110
20. Florea M, Hagemann H, Santosa G, et al. Engineering control of bacterial cellulose production using a genetic toolkit and a new cellulose producing strain. Proc Natl Acad Sci U S A,2016:113(24):E3431-40. doi:10.1073/pnas.1522985113
21. Liu M, Li S, Xie Y, et al. Enhanced bacterial cellulose production by *Gluconacetobacter xylinus* via expression of *Vitreoscilla* hemoglobin and oxygen tension regulation. Appl Microbiol Biotechnol,2018:102(3):1155-1165. doi:10.1007/s00253-017-8680-z
22. Carreira P, Mendes JAS, Trovatti E, Serafim LS, Freire CSR, Silvestre AJD. Utilization of residues from agro-forest industries in the production of high value bacterial cellulose. Bioresource Technol,2011:102(15):7354-7360.
23. Castro C, Zuluaga R, Putaux J, Caro G, Mondragon I, Gañán P. Structural characterization of bacterial cellulose produced by *Gluconacetobacter swingsii* sp. from Colombian agroindustrial wastes. Carbohy Polym,2011:84(1):96-102.
24. Ha JH, Shehzad O, Khan S, Lee SY, Park JW, Khan T. Production of bacterial cellulose by a static cultivation using the waste from beer culture broth. Korean J Chem Engi,2008:25(4):812-815.
25. Keshk S, Sameshima K. The utilization of sugar cane molasses with/ without the presence of lignosulfonate for the production of bacterial cellulose. Appl Micro Biotechnol,2006:72(2):291-e296.
26. Hong F, Qiu K. An alternative carbon source from konjac powder for enhancing production of bacterial cellulose in static cultures by a model strain *Acetobacter aceti* subsp. *xylinus* ATCC 23770. Carbohydrate Polymers,2008:72(3):545-549.
27. Fontana JD, Franco VC, De Souza SJ, Lyra IN, Souza AM. Nature of plant stimulators in the production of *Acetobacter xylinum* ("tea fungus") biofilm used in skin therapy. Appl Biochem Biotechnol,1991:28(1):341-351.
28. Karahan AG, Akoglu A, Çakir I, Kart A, Çakmakç ML, Uygun A. Some properties of bacterial cellulose produced by new native strain *Gluconacetobacter* sp. A06O2 obtained from Turkish vinegar. J Appl Polymer Sci,2011:121(3):1823-1831.
29. Rani MU, Udayasankar K, Appaiah KA. Properties of bacterial cellulose produced in grape medium by native isolate *Gluconacetobacter* sp. J Appl Polymer Sci,2011:120(5):2835-2841.
30. Zeng X, Small DP, Wan W. Statistical optimization of culture conditions for bacterial cellulose production by *Acetobacter xylinum* BPR 2001 from maple syrup. Carbohy Polym,2011:85(3):506-513.
31. Hong F, Zhu YX, Yang G, Yang XX. Wheat straw acid hydrolysate as a potential cost-effective feedstock for production of bacterial cellulose. J Chem Technol Biotechnol,2011:86(5):675-680.
32. Cacicedo ML, Castro MC, Servetas I, Bosnea L, Boura K, Tsafrakidou P, et al. Progress in bacterial cellulose matrices for biotechnological applications. Bioresour. Technol, 2016, 172–180. 10.1016/j.biortech.2016.02.07.
33. Hungund B. Production of Bacterial Cellulose from *Gluconacetobacter persimmonis* GH-2 using Dual and Cheaper Carbon Sources. J Microb Biochem Technol,2013:05(02). doi:10.4172/1948-5948.1000095
34. Keshk S, Sameshima K. The utilization of sugar cane molasses with/without the presence of lignosulfonate for the production of bacterial cellulose. Appl Microbiol Biotechnol,2006:72(2):291-296. doi:10.1007/s00253-005-0265-6
35. Tyagi N, Suresh S. Production of cellulose from sugarcane molasses using *Gluconacetobacter intermedius* SNT-1: optimization & characterization. J Clean Prod,2016:112:71-80. doi:10.1016/j.jclepro.2015.07.054
36. Shezad O, Khan S, Khan T, Park JK. Physicochemical and mechanical characterization of bacterial cellulose produced with an excellent productivity in static conditions using a simple fed-batch cultivation strategy. Carbohydr Polym,2010:82(1):173-180. doi:10.1016/j.carbpol.2010.04.052
37. Islam MU, Ullah MW, Khan S, Shah N, Park JK. Strategies for cost-effective and enhanced production of bacterial cellulose. Int J Biol Macromol,2017:102:1166-1173. doi:10.1016/j.ijbiomac.2017.04.110
38. Molina-Ramírez C, Castro C, Zuluaga R, Gañán P. Physical characterization of bacterial cellulose produced by *Komagataeibacter medellinensis* using food supply chain waste and agricultural by-products as alternative low-cost feedstocks. J Polym Environ,2018:26(2):830-837. doi:10.1007/s10924-017-0993-6
39. Krystynowicz A, Czaja W, Wiktorowska-Jezierska A, Gonçalves-Miśkiewicz M, Turkiewicz M, Bielecki S. Factors affecting the yield and properties of bacterial cellulose. J Ind Microbiol Biotechnol,2002:29(4):189-195. doi:10.1038/sj.jim.7000303.
40. Kim YJ, Kim JN, Wee YJ, Park DH, Ryu HW. Bacterial cellulose production by *Gluconacetobacter* sp. PKY5 in a rotary biofilm contactor. Appl Biochem Biotechnol,2007:137-140(1-12):529-537. doi:10.1007/s12010-007-9077-8
41. Jung JY, Khan T, Park JK, Chang HN. Production of bacterial cellulose by *Gluconacetobacter hansenii* using a novel bioreactor equipped with a spin filter. Korean J Chem Eng,2007:24(2):265-271. doi:10.1007/s11814-007-5058-4.
42. Yoshino T, Asakura T, Toda K. Cellulose production by *Acetobacter pasteurianus* on silicone membrane. J. Ferment. Bioeng, 1996, 81, 32–36.
43. Kim YJ, Kim JN, Wee YJ, Park DH, Ryu HW. Bacterial cellulose production by *Gluconacetobacter* sp. PKY5 in a rotary biofilm contactor. Appl Biochem Biotechnol,2007:137-140(1-12):529-537. doi:10.1007/s12010-007-9077-8
44. Harald T, Arthur E. Coconut: Rediscovered as Medicinal Food. Harald Tietze Publishing, 2006.
45. Sanchez PC. Philippine Fermented Foods: Principles and Technology. University of the Philippines, 2008, 378.

46. Gallegos AMA, Carrera SH, Parra R, Keshavarz T, Iqbal HMN. Bacterial cellulose. Bioresources,2016:11(2):5641-5655.
47. Sharangi AB, Datta S. Value Addition of Horticultural Crops: Recent Trends and Future Directions. Springer, 2015.
48. Tri SA. Pineapple Liquid Waste as Nata De Pina Raw Material. Makara, Teknologi,2012:16(1):63-67.
49. Shi Z, Zhang Y, Phillips GO, Yang G. Utilization of bacterial cellulose in food. Food Hydrocoll,2014:35:539-545. doi:10.1016/j.foodhyd.2013.07.012
50. Jozala AF, de Lencastre-Novaes LC, Lopes AM, et al. Bacterial nanocellulose production and application: a 10-year overview. Appl Microbiol Biotechnol,2016:100(5):2063-2072. doi:10.1007/s00253-015-7243-4
51. Kent RA, Stephens RS, Westland JA. Bacterial cellulose fiber provides an alternative for thickening and coating. Food Technol, 1991, 45(6).
52. Granger C, Leger A, Barey P, Langendorff V, Cansell M. Influence of formulation on the structural networks in ice cream. Int. Dairy J, 2005, 15, 255–262. doi: 10.1016/j.idairyj.2004.07.009
53. Paximada P, Koutinas AA, Scholten E. Effect of bacterial cellulose addition on physical properties of WPI emulsions. Comparison with common thickeners. Food Hydrocol,2016:54:245-254.
54. Guo Y, Zhang X, Hao W, et al. Nano-bacterial cellulose/soy protein isolate complex gel as fat substitutes in ice cream model. Carbohydr Polym,2018:198:620-630. doi:10.1016/j.carbpol.2018.06.078
55. Okiyama A, Motoki M, Yamanaka S. Bacterial cellulose IV. Application to processed foods. Food Hydrocol,1993:6:503-511.
56. Rios RV, Garzón R, Lannes SCS, Rosell CM. Use of succinyl chitosan as fat replacer on cake formulations. Lebenson Wiss Technol,2018:96:260-265. doi:10.1016/j.lwt.2018.05.041
57. Kumar Y, Kairam N, Ahmad T, Yadav DN. Physico chemical, microstructural and sensory characteristics of low-fat meat emulsion containing aloe gel as potential fat replacer. Int J Food Sci Technol,2016:51(2):309-316. doi:10.1111/ijfs.12957
58. Aydinol P, Ozcan T. Production of reduced-fat Labneh cheese with inulin and β-glucan fibre-based fat replacer. Int J Dairy Technol,2018:71(2):362-371. doi:10.1111/1471-0307.12456
59. Lin KW, Lin HY. Quality characteristics of Chinese-style meatball containing bacterial cellulose (nata). J Food Sci,2004:69(3):SNQ107-SNQ111. doi:10.1111/j.1365-2621.2004.tb13378.x
60. Lin SB, Chen LC, Chen HH. Physical characteristics of surimi and bacterial cellulose composite gel. J Food Process Eng,2011:34(4):1363-1379. doi:10.1111/j.1745-4530.2009.00533.x
61. Feng X, Ullah N, Wang X, et al. Characterization of bacterial cellulose by *gluconacetobacter hansenii* CGMCC 3917. J Food Sci,2015:80:2217-2227.
62. Park JK, Jung JY, Khan T. 26-Bacterial Cellulose Handbook of Hydrocolloids Woodhead Publishing Series in Food Science, Technology and Nutrition 2nd Edn. Woodhead Publishing, 2009, 724-739.
63. Sonia A, Dasan KP. EVA) Composites for Food Packaging Applications: A Study Based on Barrier and Biodegradation Behavior. J Food Engg,2013:118(1):78-89.
64. Arrieta MP, Fortunati E, Dominici F, Rayon E, Lopez J, Kenny JM. PLA-PHB/cellulose based films: Mechanical, barrier and disintegration properties. Polym Degrad Stab,2014:107:139-149. doi:10.1016/j.polymdegradstab.2014.05.010
65. Gao C, Yan T, Du J, He F, Luo H, Wan Y. Introduction of Broad Spectrum Antibacterial Properties to Bacterial Cellulose Nanofibers Via Immobilising E-Polylysine Nanocoatings. Food Hydrocol,2014:36:204-211.
66. Jipa IM, Stoica-Guzun A, Stroescu M. Controlled release of sorbic acid from bacterial cellulose based mono and multilayer antimicrobial films. LWT -Food Science and Technology,2012:47(2):400-406.
67. Adepu S, Khandelwal M. Broad-spectrum antimicrobial activity of bacterial cellulose silver nanocomposites with sustained release. J Mater Sci, 2017, 1-15.
68. Almeida DM, Prestes RA, Woiciechowski ALD, Wosiacki G. Application of bacterial cellulose conservation of minimally processed fruits. Revista Brasileira de Tecnologia Agroindustrial,2011:5(1):356-366.
69. Bandyopadhyay S, Saha N. Bacterial cellulose based greener packaging material: a bioadhesive polymeric film. Mater Res Express,2018:5:1-11.
70. Ummartyotin S, Pisitsak P, Pechyen C. Eggshell and Bacterial Cellulose Composite Membrane as Absorbent Material in Active Packaging. Intern J Polym Sci, 2016, 1-18.
71. Muangman P, Opasanon S, Suwanchot S, Thangthed O. Efficiency of Microbial Cellulose Dressing in Partial-Thickness Burn Wounds. The J Amer College Certified Wound Specialists,2011:3(1):16-19.
72. Wippermann J, Schumann D, Klemm D, Kosmehl H, Salehi-Gelani S, Ahlers T. Preliminary Results of Small Arterial Substitute Performed with a Cylindrical Biomaterial Composed of Bacteria Cellulose. Eur J Vascul Endovas Surgery,2009:37:592-596.
73. Shah N, Ul-Islama M, Khattaka WA, Parka JK. Overview of Bacterial Cellulose Composites: A Multipurpose Advanced Material. Carbohydr Polym,2013:98:1585-1598.