



“ST26943”, 2nd International Conference on Agricultural and Food Engineering, CAFEi2014”

Overview of Bacterial Cellulose Production and Application

Faezah Esa*, Siti Masrinda Tasirin, Norliza Abd Rahman

Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Abstract

Bacterial cellulose (BC), produced by aerobic bacteria received ample of attention due to its unique physiochemical properties compared to plant cellulose. Intense researches on BC mainly focus on biosynthetic process to achieve low-cost preparation and high cellulose production. BC has been used as biomaterial for medical field, electrical instrument and food ingredient. However, BC alone has limited capabilities to fulfil current demand on high-performance biomaterials. Hence, BC composite has been introduced to enhance BC properties through addition of reinforcement materials. This review discusses current knowledge in fermentation process and potential application of BC including its application in food industry.

© 2014 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/3.0/>).

Peer-review under responsibility of the Scientific Committee of CAFEi2014

Keywords: Bacterial cellulose; *acetobacter xylinum*; fermentation; composite material

1. Introduction

Cellulose is the most abundant, inexpensive and readily available carbohydrate polymer in the world, traditionally extracted from plants or their wastes. This polymer normally branches with hemicellulose and lignin has to undergo unhealthy chemical process with harsh alkali and acid treatment to obtain the pure product (Sun, 2008). Increasing demand on derivatives of plant cellulose had increased wood consumption as raw material, causing deforestation and global environmental issue (Park et al., 2003).

Although plant is the major contributor of cellulose, various bacteria are able to produce cellulose as an alternative source. Bacterial cellulose (BC) was initially reported by Brown (1988) who identified the growth of unbranched pellicle with chemically equivalent structure as plant cellulose. Due to BC structure that consist only

* Corresponding author. Tel.: +6-013-9275643.

E-mail address: faey_z@yahoo.com.my

glucose monomer, it exhibits numerous great properties such as unique nanostructure (Chen et al., 2010), high water holding capacity (Saibuatong and Phisalaphong, 2010), high degree of polymerization (Dahman et al., 2010), high mechanical strength (Castro et al., 2011) and high crystallinity (Keshk, 2014). The discovery from previous researches had clearly shown that BC and its derivatives have tremendous potential and provide a promising future in various fields such as biomedical, electronic and food industrial (Shah et al., 2013; Zhu et al., 2010).

BC is produced by acetic acid bacteria in both synthetic and non-synthetic medium through oxidative fermentation. *Acetobacter xylinum* is the most studied and the most efficient BC producer (El-Saied et al., 2004) that manage to assimilate various sugars and yields high level of cellulose in liquid medium (Ross et al., 1991; Sani and Dalman 2010; Moosavi-Nasab and Yousefi, 2011). This aerobic gram-negative bacteria actively fermented at pH 3–7 and temperature between 25 and 30°C using saccharides as carbon source (Castro et al., 2011). Rivas et al. (2004) reported that almost 30% of bacterial fermentation is belong to the cost of fermentation medium. High cost and low-yield production has limited the industrial production of BC and its commercial application. Therefore, it is important to look for a new cost-effective carbon source with shorter fermentation process for high yield BC production.

2. Bacterial cellulose structure

BC exists as a basic structure of fibril that consists of β -1→4 glucan chain with molecular formula ($C_6H_{10}O_5$) n . The glucan chains are held together by inter- and intra- hydrogen bonding (Ul-Islam et al., 2012) (Fig. 1). Microfibrils of BC were first described by Muhlethalerin 1949 and about 100 times smaller than plant cellulose (Chawla et al., 2009; Gayathry and Gopalaswamy, 2014).

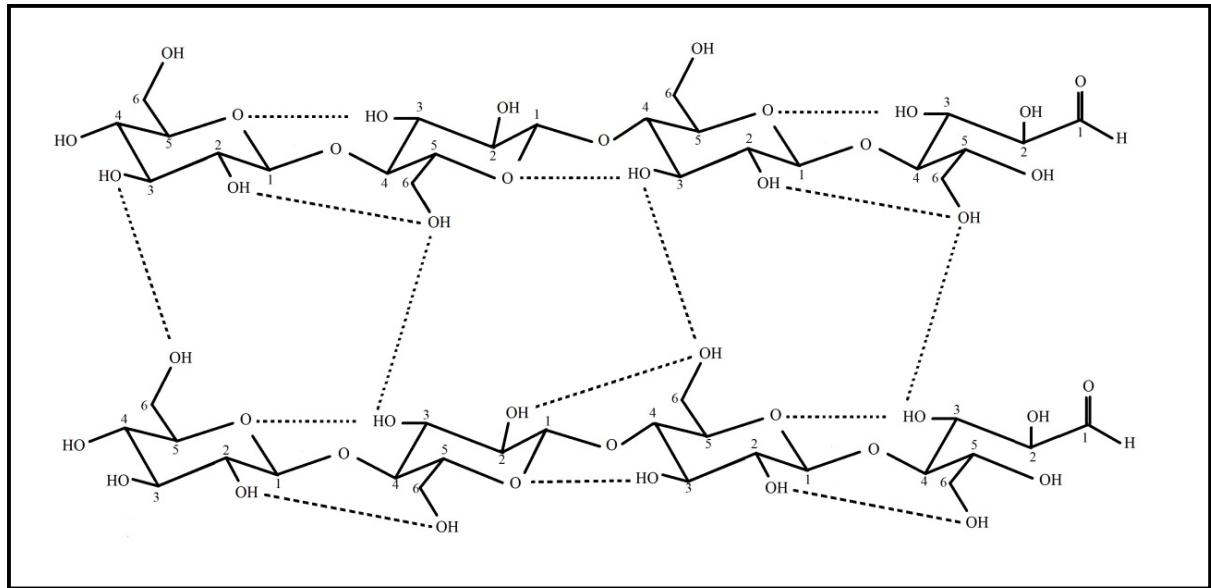


Fig. 1. Inter- and intra-hydrogen bonding of bacterial cellulose (edited from Festucci-Buselli et al. 2007).

The fibrous network of BC is made of three dimensional nanofibres that well-arranged, resulting 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 in Fig. 2 (Chawla et al., 2009). During the synthesis process, protofibrils of glucose chain are secreted through bacteria cell wall and aggregate together forming nanofibrils cellulose ribbons (Ross et al., 1991). These ribbons construct the web shaped network structure of BC with highly porous matrix (Dahman, 2009; Maria et al., 2010). The cellulose formed has abundant surface of hydroxyl groups that explaining it as hydrophilicity, biodegradability, and chemical-modifying capacity (Klemm et al., 2005). Further mechanism of BC synthesis was clearly explained by Chawla et al. (2009).

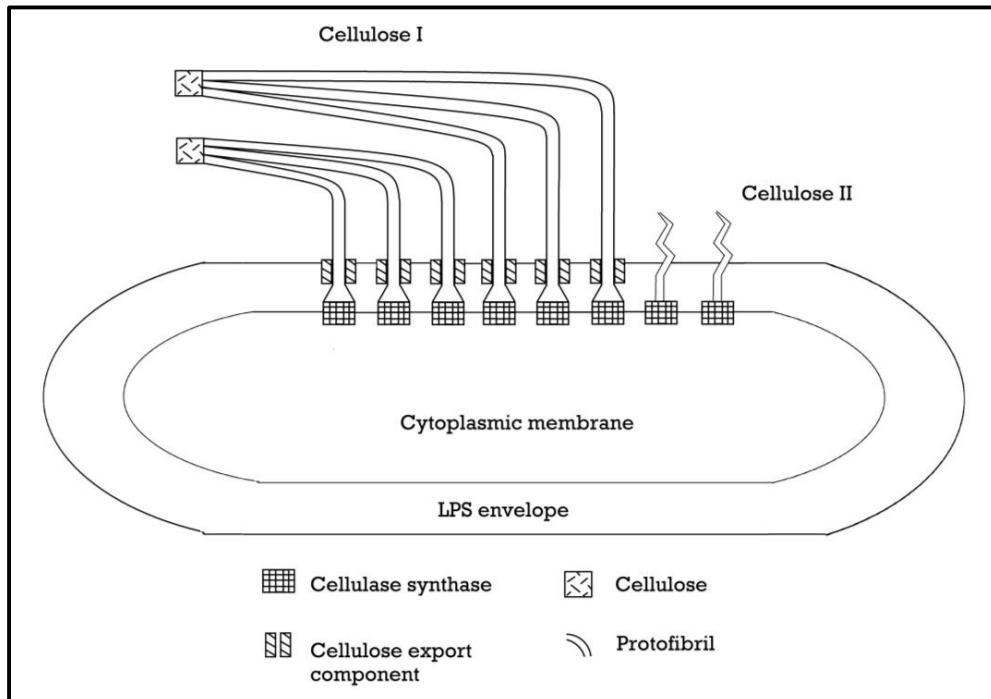


Fig. 2. Production of cellulose microfibrils by *Acetobacter xylinum* (Chawla et al. 2009).

3. Fermentation process

3.1 Culture condition

Fermentation of BC production is conducted in either static, agitated or stirred conditions. Different forms of cellulose are produced under these conditions. Three dimensional interconnected reticular pellicle was reported under static condition while both agitated and stirred condition produced irregular shape sphere-like cellulose particle (SCP) (Tanskul et al., 2013). The process of cellulose formation under static condition is regulated by air supply from medium surface and the yield depends on the carbon source concentration moderately (Budhiono et al., 1999). The increasing of growth time will increase the formation of BC along with hydrogen and C-H bonding (Sheykhnazari et al., 2011). Synthesis of BC reach its limit when the pellicle growth downward and entraps all bacteria. Bacteria become inactive due to insufficient oxygen supply (Borzani and Desouza, 1995). Semi-continuous process in static condition is recommended at industrial scale as it manage to increase BC productivity compared to continuous process (Çakar et al., 2014).

In contrast, due to low yield of the static production, most of cellulose used in commercial purpose is generated through agitated fermentation. Agitated condition causes formation of SCP, an irregular forms of cellulose either in fibrous suspension, spheres, pellets or irregular masses (Yan et al., 2008, Wu and Lia, 2008). The SCP has lower crystallinity, mechanical strength and degree of polymerization compared to pellicle from static culture (Shi et al., 2013). The altered microfibrils organization was proposed related to the disruption effects of aeration on the hydrogen bonds formations between cellulose (Booten et al., 2008). Study by Hu et al. (2013) found that the number of SCP decreased with the increasing volume of inoculum while different initial glucose concentration only gave an impact to the mean diameters of SCP. However, the mechanism of SCP formation is still remain unknown.

3.2 Culture medium

In biorefinery concept, a progressive transition to economically renewable materials as feedstock for chemical, materials and fuels is predicted to occur due to depletion of fossil resources (Octave and Thomas, 2009). In order to find a new economical culture medium for industrial scale production of BC, many studies have focused on agriculture waste and industrial by-product as potential medium (Kurosumi et al., 2009; Gomes et al., 2013; Çakar et al., 2014). Some of them have been proven as beneficial carbon source for BC production such as waste beer yeast (Lin et al., 2014), dry oil mill residue (Gomes et al., 2013), thin stillage (Wu and Liu, 2012), grape skin (Carreira et al., 2011) and maple syrup (Zeng et al., 2011). Besides that, the use of such products gives a positive impact on corresponding industry by decreasing the environmental problems associate with disposal of waste. In addition, medium supplementation with nitrogen and phosphorus sources were confirmed would increase BC production (Gomes et al., 2013).

The usage of glucose as carbon source during BC production is associated with the formation of gluconic acid as by-product in the culture medium. This by-product will decrease the pH of the culture and negatively affect the quantity of BC production. However the presence of antioxidant and polyphenolic compounds manages to inhibit the gluconic acid formation (Keshk and Sameshima, 2006).

4. Bacterial cellulose composite

BC has been applied in multiple field such as wound dressing (Muangman et al., 2011), blood vessel regeneration (Wippermann et al., 2009), and paper restoration (Santos et al., 2014). Although BC has unique properties, there is limitation that restricts its applications such as lack of antibacterial properties, optical transparency, and stress bearing capability. To overcome these limitations, BC composite has been introduced which consist of a matrix and reinforcement materials. BC owns a porous nature arrangement of fibres. It acts as matrix for housing a variety of particles from different reinforcement materials. The anchored reinforcement materials provide an additional properties to BC that impart its nature biological and physicochemical properties (Shah et al., 2013).

BC possess a potential as both matrix and reinforcement materials. Various BC composites have been synthesized through either in situ or ex situ methods. For the in situ method, reinforcement materials is added to the polymer during its synthesis (Saibuatong and Philsalaphong, 2010) while in the ex situ process, BC is impregnated with reinforcement materials (Ul-Islam et al., 2012). As shown in Table 1, various BC composites are synthesized with different function. BC composite can be either organic or inorganic material such as polymers (Kim et al., 2011), metal or metal oxides (Maneerung et al., 2007), solid materials (Meng et al., 2009) and nanomaterials (Yan et al., 2008).

Table 1. Bacterial cellulose composites and application.

No.	Application field	Reinforcement material	Function	References
1.	Electronic	Graphite nanoplatelet	Electrical conductivity	Zhou et al., 2013
2.	Electronic	Poly-4-styrene sulfonic acid	Redox flow battery	Gadim et al., 2014
3.	Biomedical / Industrial	Chitosan	Nanofilm	Fernandes et al., 2009
4.	Biomedical	Hydroxyapatite	Bone tissue engineering	Tazi et al., 2012
5.	Biomedical	Silver nanoparticles	Antimicrobial wound dressing	Wu et al., 2014, Zhang et al., 2013
6.	Biomedical	Paraffin	Bone scaffolding	Zaborowska et al., 2010
7.	Electronic	Polyurethane	Film substrate of light emitting diod	Ummartyotin et al., 2012.

5. Application of bacterial cellulose in food industry

BC is traditionally used to make nata de coco, an indigenous dietary fiber of South-East asia that served as gelatinous cube. Nata de coco has textural properties like chewy, soft and smooth surface. It has no cholesterol, low in fat and low calories. During the production process, BC was synthesized in static culture of coconut water (Jagannath et al., 2008). Coconut water served as carbon source for *Acetobacter xylinum* and later converted to extracellular cellulose (Cannon and anderson, 1991). The thick sheet of cellulose was washed, boiled and cooked in sugar syrup for food applications such as desserts, fruit cocktails and jellies. High fiber supplement mixture of nata

de coco and cereal was reported able to reduced lipid level of consumer (Mesomya et al., 2006). On the other hand, nata de coco is also a very promising medium for continuous bioethanol production in term of structural strength and cost effectiveness (Montealegre et al., 2012).

Packaging plays an important role to protect and preserve the food. Bio-based materials in packaging industry is more preferable nowadays due to concern arise on non-biodegradable packaging impact to the environment. BC has been identified as one of the suitable material (Tang et al., 2012) as it consist of fine network, biodegradable (Sonia and Dasan, 2013), and high water resistance performance (Arrieta et al., 2014). Even BC is an excellent choice for food packaging, unfortunately it has no antibacterial and antioxidant properties to prevent food contamination. Therefore, BC composites are used to gain these properties (Gao et al., 2014). Further BC application are summarized in Table 2.

Table 2. Application of modified bacterial cellulose (BC) and its composites in food industry.

No.	Materials	Function	Types of food	References
1.	BC/nisin	Antimicrobial food packaging	meat	Nguyen et al., 2008
2.	BC/polylysine	Biodegradable food packaging	sausage	Zhu et al., 2010
3.	BC	Emulsifier	surimi	Lin et al., 2011
4.	Carboxymethylcellulose	Regulate dough rheology	Flour dough	Correa et al., 2010
5.	Hydroxypropyl methyl cellulose	Texture enhancer	Whipped cream	Zhao et al., 2009
6.	Methyl cellulose	Enhancing shelf life	Egg	Suppakul et al., 2010
7.	Methyl cellulose	Enhance bioavailability	Vitamin C	Perez et al., 2013

6. Conclusions

Acetic acid bacteria are capable to replace plant as an alternative source of cellulose through oxidative fermentation under static, agitated and stirred conditions. However, high cost and low-yield production have limits its commercial applications and industry potentials. Therefore, researches have focus on agriculture waste and industrial by-product as new cost-effective carbon sources. Besides that, the modification and incorporation of particles in BC matrix enhance its nature physiochemical properties and bring up the new opportunity for applications.

References

- Arrieta, M.P., Fortunati, E., Dominici, F., Rayón, E., López, J., Kenny, J.M., 2014. PLA-PHB/Cellose Based Films: Mechanical, Barrier and Disintegration Properties. *Polymer Degradation and Stability*. doi: 10.1016/j.polymdegradstab.2014.05.010
- Bootten, T.J., Harris, P.J., Melton, L.D., Newman, R.H., 2008. WAXS and ¹³C NMR Study of Glucoacetobacter Xylinus Cellulose in Composites with Tamarind Xyloglucan. *Carbohydrate Research* 343(2), 221–229.
- Borzani, W., Souza, S.J., 1995. Mechanism of The Film Thickness Increasing During The Bacterial Production of Cellulose on Non-agitated Liquid Media. *Biotechnology Letters* 17, 1271–1272.
- Brown, A.J., 1988. An Acetic Ferment which forms Cellulose. *Chemical Society* 49, 432–439.
- Budhiono, A., Rosidi, B., Taher, H., Iguchi, M., 1999. Kinetic aspects of Bacterial Cellulose Formation in Nata-De-Coco Culture System. *Carbohydrate Polymers* 40, 137–143.
- Çakar, F., Özer, I., Aytekin, A.Ö., Sahin, F., 2014. Improvement Production of Bacterial Cellulose by Semi-Continuousprocess in Molasses Medium. *Carbohydrate Polymers* 106, 7–13.
- Cannon, R.E., anderson, S.M., 1991. Biogenesis of Bacterial Cellulose. *Critical Reviews in Microbiology* 17(6), 435–447.
- Carreira, P., Mendes, J.A., Trovatti, E., Serafim, L.S., Freire, C.S., Silvestre, A.J., Neto, C.P., 2011. Utilization of Residues from Agro-forest Industries In The Production of High Value Bacterial Cellulose. *BioresourcesTechnology* 102(15), 7354–7360.
- Castro, C., Zuluaga, R., Putaux, J.L., Caro, G., Mondragon, I., Gañán, P., 2011. Structural Characterization of Bacterial Cellulose Produced by *gluconacetobacter Swingsii* Sp. From Colombian Agroindustrial Wastes. *Carbohydrate Polymers* 84(1), 96–102.
- Chawla, P.R., Bajaj, I.B., Survase, S.A., Singhal, R.S., 2009. Microbial Cellulose: Fermentative Production and Applications. *Food Technology Biotechnology* 47(2), 107–124.
- Chen, P., Cho, S.Y., Jin, H.J., 2010. Modification and Applications of Bacterial Celluloses in Polymer Science. *Macromolecular Research* 18, 309–320.
- Correa, M.J., Añón, M.C., Pérez, G.T., Ferrero, C., 2010. Effect of Modified Celluloses on Dough Rheology and Microstructure. *Food Research International* 43, 780–787.
- Dahman, Y., 2009. Nanostructured Biomaterials and Biocomposites from Bacterial Cellulose Nanofibers. *Journal of Nanoscience and Nanotechnology* 9, 5105–5122.
- Dahman, Y., Jayasuriya, K.E., Kalis, M., 2010. Potential of Biocellulose Nanofibers Production from Agricultural Renewable Resources: Preliminary Study. *Applied Biochemistry and Biotechnology* 162(6), 1647–1659.
- El-Saied, H., Basta, A.H., Gobran, R.H., 2004. Research Progress in Friendly Environmental Technology for the Production of Cellulose

- Products (Bacterial Cellulose and Its Application). *Polymer–Plastics Technology and Engineering* 43(3), 797–820.
- Fernandes, S.C.M., Oliveira, L., Freire, C.S.R., Silvestre, A.J.D., Neto, C.P., Gandinia, A., Desbrieres, J., 2009. Novel Transparent Nanocomposite Films Based on Chitosan and Bacterial Cellulose. *Green Chemicals* 11, 2023–2029.
- Festucci-Buselli, R.A., Otoni, W.C., Joshi, C.P., 2007. Structure, Organization, and Functions of Cellulose Synthase Complexes in Higher Plants. *Brazilian Journal of Plant Physiology* 19(1).
- Gadim, T.D.O., Figueiredo, A.G.P.R., Rosero-Navarro, N.C., Vilela, C., Gamelas, J.A.F., Barros-Timmons, A., Neto, C.P., Silvestre, A.J.D., Freire, C.S.R., Figueiredo, F.M.L., 2014. Nanostructured Bacterial Cellulose–Poly(4-Styrene Sulfonic Acid) Composite Membranes with High Storage Modulus and Protonic Conductivity. *ACS Applied Materials and Interfaces* 6(10), 7864–7875.
- Gayathry, G., Gopalaswamy, G., 2014. Production and Characterization of Microbial Cellulosic Fibre From *Acetobacter xylinum*. *Indian Journal of Fibre and Textile Research* 39, 93–96.
- Gao, C., Yan, T., Du, J., He, F., Luo, H., Wan, Y., 2014. Introduction of Broad Spectrum Antibacterial Properties to Bacterial Cellulose Nanofibers Via Immobilising E-Polylysine Nanocoatings. *Food Hydrocolloids* 36, 204–211.
- Gomes, F.P., Silva, N.H.C.S., Trovatti, E., Serafim, L.S., Duarte, M.F., Silvestre, A.J.D., Neto, C.P., Freire, C.S.R., 2013. Production of Bacterial Cellulose by *Gluconacetobacter sacchari* using Dry Olive Mill Residue. *Biomass and Bioenergy* 55, 205–211.
- Hu, Y., Catchmark, J.M., Vogler, E.A., 2013. Factors Impacting the formation of Sphere-Like Bacterial Cellulose Particles and Their Biocompatibility for Human Osteoblast Growth. *Biomacromolecules* 14 (10), 3444–3452.
- Jagannath, A., Kalaiselvan, A., Manjunatha, S.S., Raju, P.S., Bawa, A.S., 2008. The Effect of pH, Sucrose and Ammonium Sulphate Concentrations on the Production of Bacterial Cellulose (Nata-De-Coco) by *Acetobacter xylinum*. *World Journal of Microbiology and Biotechnology* 24(11), 2593–2599.
- Keshk, S.M., 2014. Bacterial Cellulose Production and Its Industrial Applications. *Bioprocess Biotechnology* 4, 2.
- Keshk, S.M., Sameshima, K., 2006. Influence of Lignosulfonate on Crystal Structure and Productivity of Bacterial Cellulose in a Static Culture. *Enzyme Microbiology Technology* 40, 4–8.
- Kim, J., Cai, Z., Lee, H.S., Choi, G.S., Lee, D.H., Jo, C., 2011. Preparation and Characterization of a Bacterial Cellulose/Chitosan Composite for Potential Biomedical Application. *Journal of Polymer Research* 18(4), 739–744.
- Klemm, D., Heublein, B., Fink, H.P., Bohn, A., 2005. Cellulose: Fascinating Biopolymer and Sustainable Raw Material. *Angewandte Chemie – International Edition* 44(22), 3358–3393.
- Kurosumi, A., Sasaki, C., Yamashita, Y., Nakamura, Y., 2009. Utilization of Various Fruit Juices as Carbon Source for Production of Bacterial Cellulose by *Acetobacter xylinum* NBRC 13693. *Carbohydrate Polymers* 76(2), 333–335.
- Lin, D., Lopez-Sanchez, P., Li, R., Li, Z., 2014. Production of Bacterial Cellulose by *Gluconacetobacter hansenii* CGMCC 3917 Using only Waste Beer Yeast as Nutrient Source. *Bioresource Technology* 151, 113–119.
- Lin, S.B., Chen, L.C., Chen, H.H., 2011. Physical Characteristics of Surimi and Bacterial Cellulose Composite Gel. *Journal of Food Process Engineering* 34, 1363–1379.
- Maneerung, T., Tokura, S., Rujiravanit, R., 2007. Impregnation of Silver Nanoparticles into Bacterial Cellulose for Antimicrobial Wound Dressing. *Carbohydrate Polymers* 72(1), 43–51.
- Maria, L.C.S., Santos, A.L.C., Oliveira, P.C., Valle, A.S.S., 2010. Preparation and Antibacterial Activity of Silver Nanoparticles Impregnated in Bacterial Cellulose. *Polímeros: Ciéncia e Tecnologia* 20, 72–77.
- Meng, N., Zhou, N. L., Zhang, S. Q., Shen, J., 2009. Synthesis and Antimicrobial Activities of Polymer/Montmorillonite–Chlorhexidine Acetate Nanocomposite Films. *Applied Clay Science* 42, 667–670.
- Mesomya, W., Pakpeankitvatana, V., Komindr, S., Leelahakul, P., Cuptapun, Y., Hengsawadi, D., Tammarate, P., Tangkanakul, P., 2006. Effects of Health Food From Cereal and Nata De Coco on Serum Lipids In Human. *Songklanakarin. Journal of Science Technology* 28(1), 23–28.
- Montealegre, C.M., Dionisio, E.R., Sumera, L.V., Adolacion, J.R.T., Leon, R.D., 2012. Continuous Bioethanol Production using Saccharomyces cerevisiae Cells Immobilized In Nata De Coco (Biocellulose). *IPCBEE* (35).
- Moosavi-Nasab, M., Yousefi, M., 2011. Biotechnological Production of Cellulose by *Gluconacetobacter Xylinus* from Agricultural Waste. *Iranian Journal of Biotechnology* 9(2), 94–101.
- Muangman, P., Opasanon, S., Suwanchot, S., Thangthed, O., 2011. Efficiency of Microbial Cellulose Dressing in Partial-Thickness Burn Wounds. *The Journal of the American College of Certified Wound Specialists* 3(1), 16–19.
- Nguyen, V.T., Gidley, M.J., Dykes, G.A., 2008. Potential of a nisin-containing bacterial cellulose film to inhibit Listeria monocytogenes on processed meats. *Food Microbiology* 25, 471–478.
- Octave, S., Thomas, D., 2009. Biorefinery: toward an industrial metabolism. *Biochimie* 91, 659–664.
- Park, J.K., Park, Y.H., Jung, J.Y., 2003. Production of bacterial cellulose by *Gluconacetobacter hansenii* PJK isolated from rotten apple. *Biotechnology and Bioprocess Engineering* 8(2), 83–88.
- Pérez, C.D., De'Nobili, M.D., Rizzo, S.A., Gershenson, L.N., Descalzo, A.M., Rojas, A.M., 2013. High Methoxyl Pectin–Methyl Cellulose Films with Antioxidant Activity at a Functional Food Interface. *Journal of Food Engineering* 116, 162–169.
- Rivas, B., Moldes, A.B., Domínguez, J.M., Parajó, J.C., 2004. Development of Culture Media Containing Spent Yeast Cells of debaryomyces Hansenii and Corn Steep Liquor for Lactic Acid Production with *Lactobacillus rhamnosus*. *International Journal of Food Microbiology* 97(1), 93–98.
- Ross, P., Mayer, R., Benziman, M., 1991. Cellulose Biosynthesis and Function In Bacteria. *Microbiological Reviews* 55(1), 35–58.
- Saiabutong, O.A., Phisalaphong, M., 2010. Novo Aloe Vera-Bacterial Cellulose Composite Film From Biosynthesis. *Carbohydrate Polymers* 79(2), 455–460.
- Sani, A., Dahman, Y., 2010. Improvements in The Production of Bacterial Synthesized Biocellulose Nanofibres Using Different Culture Methods. *Journal of Chemical Technology and Biotechnology* 85(2), 151–164.
- Santos, S.M., Carbajo, J.M., Quintana, E., Ibarra, D., Gomez, N., Ladero, M., Eugenio, M.E., Villar, J.C., 2014. Characterization of Purified Bacterial Cellulose Focused on Its Use on Paper Restoration. *Carbohydrate Polymers*. doi: 10.1016/j.carbpol.2014.03.064.
- Shah, N., Ul-Islama, M., Khattaka, W.A., Parka, J.K., 2013. Overview of Bacterial Cellulose Composites: A Multipurpose Advanced Material. *Carbohydrate Polymers* 98, 1585–1598.
- Sheykhnazaria, S., Tabarsaa, T., ashorib, A., Shakeric, A., Golalipourd, M., 2011. Bacterial Synthesized Cellulose Nanofibers; Effects of Growth

- Times and Culture Mediums on The Structural Characteristics. Carbohydrate Polymers 86, 1187– 1191.
- Shi, Q.S., Feng, J., Li, W.R., Zhou, G., Chen, A.M., Ouyang, Y.S., Chen, Y.B. 2013. Effect of Different Conditions on the Average Degree of Polymerization of Bacterial Cellulose Produced by *Gluconacetobacter Intermedius BC-41*. Cellulose Chemical Technology 47(7-8), 503-508.
- Sonia, A., Dasan, K.P., 2013. Celluloses Microfibers (CMF)/Poly (Ethylene-Co-Vinyl Acetate) (EVA) Composites for Food Packaging Applications: A Study Based on Barrier and Biodegradation Behavior. Journal of Food Engineering 118(1), 78-89.
- Sun, R.C., 2008. Detoxification of Biomass of Bioethanol. Bioresources 4(2), 452-455.
- Suppakul, P., Jutakorn, K., Bangchokedee, Y., 2010. Efficacy of Cellulose-Based Coating on Enhancing The Shelf Life of Fresh Eggs. Journal of Food Engineering 98, 207–213.
- Tang, X., Kumar, P., Alavi, S., Sandeep, K., 2012. Recent Advances in Biopolymers and Biopolymer-based Nanocomposites for Food Packaging Materials. Critical Reviews in Food Science and Nutrition 52, 426–442.
- Tanskul, S., Amorntharee, K., Jaturonlak, N., 2013. A New Cellulose-Producing Bacterium, *Rhodococcus Sp. MI 2*: Screening and Optimization of Culture Conditions. Carbohydrate Polymers 92(1), 421-428.
- Tazi, N., Zhang, Z., Messaddeq, Y., Almeida-Lopes, L., Zanardi, L.M., Levinson, D., Rouabchia, M., 2012. Hydroxyapatite Bioactivated Bacterial Cellulose Promotes Osteoblast Growth and the formation of Bone Nodules. AMB Express 2, 61.
- Ul-Islam, M., Khan, T., Park, J.K., 2012. Water Holding and Release Properties of Bacterial Cellulose Obtained by in Situ and ex Situ Modification. Carbohydrate Polymers 88(2), 596–603.
- Ummartyotin, S., Juntarob, J., Sainb, M., Manuspiaay, H., 2012. Development of Transparent Bacterial Cellulose Nanocomposite Film as Substrate for Flexible Organic Light Emitting Diode (OLED) Display. Industrial Crops and Products 35, 92– 97.
- Wippermann, J., Schumann, D., Klemm, D., Kosmehl, H., Salehi-Gelani, S., Ahlers, T., 2009. Preliminary Results of Small Arterial Substitute Performed with a Cylindrical Biomaterial Composed of Bacteria Cellulose. European Journal of Vascular and Endovascular Surgery 37, 592- 596.
- Wu, J., Zheng, Y., Song, W., Luan, J., Wen, X., Wu, Z., Chen, X., Wang, Q., Guo, S., 2014. In Situ Synthesis of Silver-Nanoparticles/Bacterial Cellulose Composites for Slow-Released Antimicrobial Wound Dressing. Carbohydrate polymer 102, 762-771.
- Wu, J.-M., Liu, R.-H., 2012. Thin Stillage Supplementation Greatly Enhances Bacterial Cellulose Production by *Gluconacetobacter xylinus*. Carbohydrate Polymers 90(1), 116-121.
- Wu, S.C., Lia, Y. K., 2008. Application of Bacterial Cellulose Pellets in Enzyme Immobilization. Journal of Molecular Catalysis B: Enzymatic 54(3–4), 103–108.
- Yan, Z., Chen, S., Wang, H., Wang, B., Jiang, J., 2008. Biosynthesis of Bacterialcellulose/Multi-Walled Carbon Nanotubes in Agitated Culture. Carbohydrate Polymers 74, 659–665.
- Zaboroweska, M., Bodin, A., Backdahl, H., Popp, J., Goldstein, A., Gatenholm, P., 2010. Microporous Bacterial Cellulose as a Potential Scaffold for Bone Regeneration. Acta Biomaterialia 6, 2540-2547
- Zeng, X., Small, D.P., Wan, W., 2011. Statistical Optimization of Culture Conditions for Bacterial Cellulose Production by *Acetobacter xylinum Bpr 2001* From Maple Syrup. Carbohydrate Polymers 85(3), 506-513.
- Zhang, X., Fanga, Y., Chena, W., 2013. Preparation of Silver/Bacterial Cellulose Composite Membrane and Study on Its Antimicrobial Activity. Synthesis and Reactivity in Inorganic, Metal-Organic, and Nano-Metal Chemistry 43(7), 907-913.
- Zhao, Q., Zhao, M., Li, J., Yang, B., Su, G., Cui, C., Jiang, Y., 2009. Effect of Hydroxypropyl Methylcellulose on the Textural and Whipping Properties of Whipped Cream. Food Hydrocolloids 23, 2168–2173.
- Zhou, T., Chen, D., Jiu, J., Nge, T.T., Sugahara, T., Nagao, S., Koga, H., Nogi, M., 2013. Electrically Conductive Bacterial Cellulose Composite Membranes Produced by the Incorporation of Graphite Nanoplatelets in Pristine Bacterial Cellulose Membranes. Polymer Letters 7(9), 756– 766.
- Zhu, H., Jia, S., Yang, H., Tang, W., Jia, Y., Tan, Z., 2010. Characterization of Bacteriostatic Sausage Casing: A Composite of Bacterial Cellulose Embedded with Polylysine. Food Science and Biotechnology 19, 1479-1484.

Accepted for oral presentation in CAFEi2014 (December 1-3, 2014 – Kuala Lumpur, Malaysia) as paper 309.