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AN OVERVIEW OF BACTERIAL CELLULOSE APPLICATIONS

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ABSTRACT

Biocellulose is a strong polymer consisting of nanofibrillar structures causing a large specific surface area and a microporous structure. This, in turn, creates ample opportunities for its modification, and, consequently, the production of various composite materials with significantly better characteristics. Unlike plant cellulose, bacterial doesn't contain lignin and hemicellulose and, accordingly, is fairly pure, neutral and biocompatible. In addition, bacterial cellulose is non-toxic, a biodegradable polymer that is inert to human metabolism.

Biocellulose is a valuable biopolymer for the production of food, textiles, medicine, and agriculture due to its unique properties. Microbial cellulose is synthesized by representatives of the genera *Agrobacterium, Achromobacter, Aerobacter, Enterobacter, Sarcina, Rhizobium, Pseudomonas, Salmonella, Alcaligenes and Myxedema*. But the classic producer of this material is bacteria of the genus *Komagataeibacter*: *Komagataeibacter xylinus, Komagataeibacter hansenii, Komagataeibacter kombuchae, Komagataeibacter intermedius.* This review article presents the current information about of biocellulose based on previous work that has been carried out to improve the production of biocellulose and the possibility of its application in various fields of activity. The physicochemical properties of biocellulose are discussed. Current and potential applications of the biopolymer in the textile and pharmacological industry, cosmetology are presented.

Key words: biocellulose, bacterial cellulose, biopolymer, *Komagataeibacter*, gel film.

INTRODUCTION

Cellulose is a natural polymer that is synthesized by plants, also fungi, algae, and bacteria. Cellulose is rarely found in the structure of a bacterial cell, but it is the main component of the cell wall of plants and is found in seed shells, wood, etc. The cellulose macromolecules are constructed from an unbranched D-glucose chain, which is connected to each other by a 1,4-β-glycosidic linkage in a linear form. Polymer chains of fiber are connected to each other in a larger structure – microfibrils. In cellulose, the length of the polymer chains depends on the nature of the producer and accordingly differs among themselves. Particular attention is attracted to bacterial cellulose, it differs from others in a number of unique properties, thanks to which it is widely used in various branches of the national economy and world practice [1].

There are four main sources of cellulose. The bulk of cellulose is isolated from plants. The second source is the biosynthesis of cellulose from various microorganisms, algae, and fungi. The remaining two are less common, the first is an enzymatic synthesis in vitro beginning with cellobiose fluoride and chemosynthesis from glucose by opening the ring polymerization of benzylated and pivaloylated derivatives.

The molecular form of plant cellulose and bacterial cellulose is the same $(C_6H_{10}O_5)_n$, however, they differ in their physical and chemical properties (fig. 1). Bacterial cellulose differs from plant cellulose by its high crystallinity, ultrathin structure, high water absorbing capacity and mechanical strength in the wet state [2, 3].

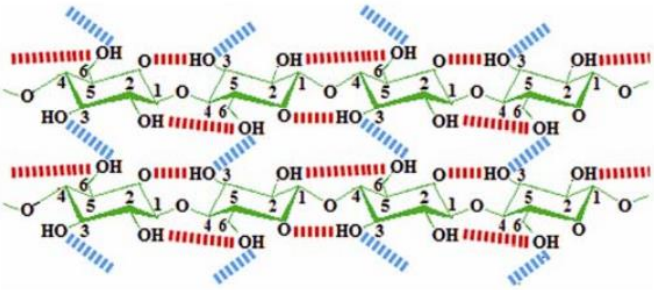


Fig. 1. Molecular structure of cellulose showing the β-1-4 glucopyranase molecule and the dimolecular cellobiose unit in the linear polymer. The intra- and inter-chain weak hydrogen bonds are shown by broad dashed lines [3]

Most often bacterial cellulose is produced by strains of the bacterium *Komagataeibacter (formerly Gluconacetobacter)* [4] *xylinus*, which is a strictly aerobic gram-negative rod. Bacterial cellulose produced with *Komagataeibacter xylinus* has a very high degree of purity and does not contain hemicellulose, lignin, waxes, and pectins [1, 2, 3].

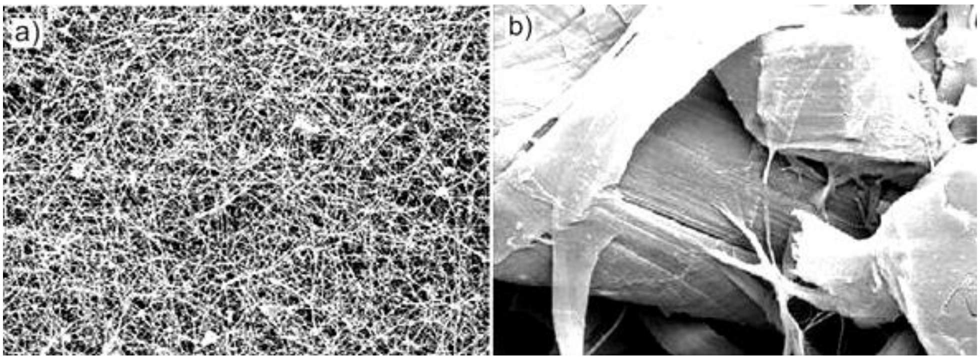
The first studies on *K. xylinum* as a producer of bacterial cellulose were initiated by Hestrin, who proved that *Komagataeibacter* cells in a lyophilized state in the presence of glucose and oxygen synthesize cellulose. After this study in 1957, Colvin discovered the synthesis of cellulose in samples containing acellular extracts of *Komagataeibacter xylinum*, in the presence of glucose and ATP [3].

Komagataeibacter xylinus produces two forms of cellulose: cellulose 1 - ribbon-like polymer and cellulose 2 – thermodynamically stable amorphous polymer. Nanofibril structure of bacterial cellulose is responsible for high tensile strength, the high degree of polymerization, and also for crystallinity. Bacterial cellulose due to the properties described above is used in many areas, for example as a paper industry, the medical field in particular in the delivery of medicines, in the food industry, as nanocomposites and in the field of cosmetology.

Bacterial cellulose in the food industry is widely used as a powder as a safety additive (GRAS – Generally Regarded As Safe) or as a food ingredient. By adding a small amount of bacterial cellulose to the products, it is possible to impart good dispersion and suspension stability, and also by maintaining the shape, one can get a feeling of fullness in the mouth when consumed.

In the past few years, many producers of extracellular bacterial cellulose have been isolated, most of them belonging to the family *Acetobacteriaceae*. Since the bacteria of the family *Acetobacteriaceae* synthesize extracellular cellulose, it can be easily separated from cells and used in the future. In the family of *Acetobacteriaceae*, producers of the genus *Komagataeibacter*: *Komagataeibacter xylinus, Komagataeibacter hansenii, Komagataeibacter kombuchae, Komagataeibacter intermedius*, etc. deserve special attention [1].

Bacterial cellulose can be obtained in a higher degree of purity and it exhibits a high degree of polymerization and crystallinity index, so bacterial cellulose is more preferable than plant cellulose. Since bacterial cellulose is more durable and water retaining capacity, it is used above for paper, acoustic columns and in the food industry for the preparation of desserts. Fibrils of bacterial cellulose are 100 times thinner than plant cellulose, this makes it highly porous material, due to this property bacterial cellulose is used for the transfer of antibiotics and other drugs, while at the same time is an effective physical barrier against any external infection (fig. 2) [5, 6].



a – bacterial cellulose; b – plant cellulose

Fig. 2. The thickness of fibrils [5]

According to S.Bielecki, bacterial cellulose due to its high purity, the high degree of crystallinity (its density ranges from 300 to 900 kg/m^3), high absorption and retention ability is a unique polymer. In addition, bacterial cellulose is non-toxic, a biodegradable polymer that is inert to human metabolism [2].

FIELD OF APPLICATION OF BACTERIAL CELLULOSE

Due to all the properties described above, bacterial cellulose can be used in any field as an alternative to plant cellulose. At present extracellular bacterial cellulose is widely used in several branches of the national economy in the world practice (fig. 3).

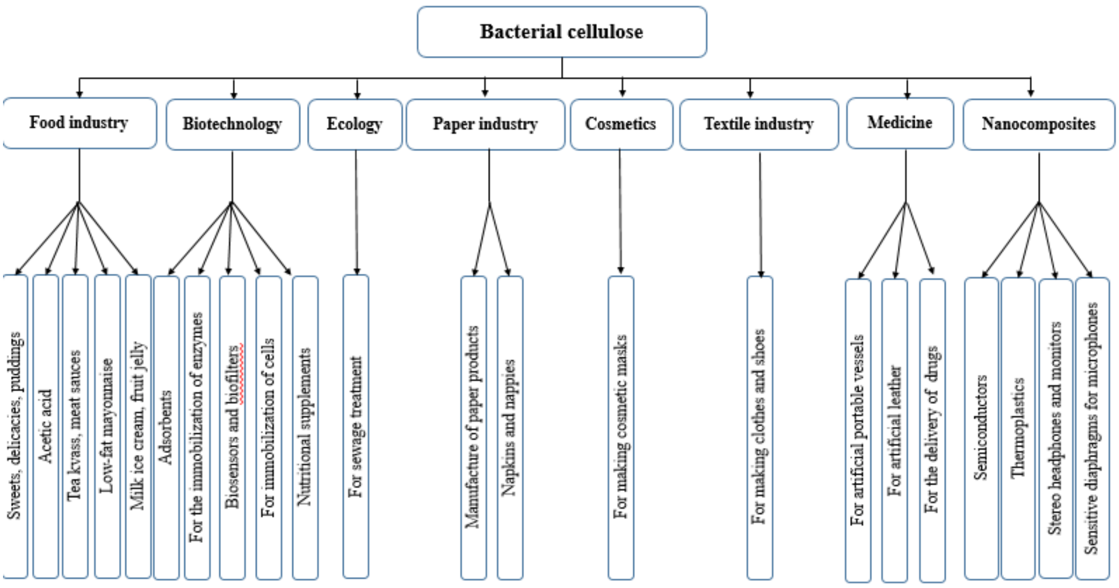


Fig. 3. Application of bacterial cellulose [7]

USING OF BACTERIAL CELLULOSE IN MEDICINE

Due to their valuable properties, bacterial nanocellulose promoted the development of medicine around the world. Many scientists have proved that bacterial cellulose is not toxic, so this material is widely used in medicine (fig. 4).

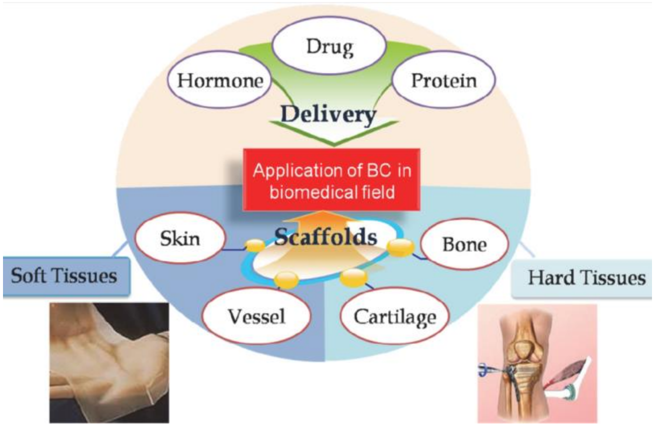


Fig. 4. Using of bacterial cellulose in medicine [7]

Bioactive cartilage implants - proteolytic enzymes, cytokines and reactive oxygen species are removed; protects the body from carcinogenesis and prevents the appearance of inflammation. An example of a cartilage made of bacterial cellulose can be a septum of the nose, an ear, intervertebral discs, etc. It is widely used in reconstructive and reconstructive surgery. Since the cartilage is slightly widened in children, and in adults, degenerative changes often occur, bioactive cartilage implants are more often used for adults. Adults are looking for such materials that are suitable for prosthetics and with a complete non-allergic reaction (fig. 5).

Fig. 5. Examples of cartilage implants, ear, nose and facial bioactivity made from bacterial cellulose [7]

Prototypes of blood vessels - a tube 5-25 cm long, which is well stable and mechanically strong and resistant to water, other liquids, ions, small particles; such blood vessels are sterilized in the usual way; most often in medicine, they are used as neurotransmitters. Natural bacterial nanocellulose has mechanical properties, these include tear resistance and shape retention, these qualities are much better than many artificial materials. Bacterial nanocellulose treated in film or in a sheet, when compared with organic sheets, such as polypropylene or cellophane, shows an excellent high mechanical strength (fig. 6) [7].

Fig. 6. A tube acting as a blood vessel made of bacterial cellulose, represented on a red glass, symbolizing the blood flow [7]

Dressing materials – used in medicine as a band-aid or as a large bandage; By properties biocompatible, sterile, porous and flexible; Such material allows the wounds to breathe, treat and prevent the formation of scabs and scars; also, reduces pain, protects the skin from various infections and does not cause loss of body fluid; It is also used as a protective surface for firefighters, who are often exposed to burns (fig. 7) [8].

Properties that are inherent in bacterial nanocellulose, and this is the mechanical strength, the transmission of gases and liquids and low annoyance to the skin, allow it to be used as an artificial skin for the temporary covering of ulcers and wounds. Biofill® produces bacterial nanocellulose for a wide range of applications in surgery and implantation of teeth. In the same company, the second and third degrees of burns, ulcers and other cases are successfully treated. Advantages of bacterial nanocellulose produced by Biofill® are rapid pain relief, close adhesion to the wound, noticeably rapid healing, reduction in wound size after surgery, wound control (transparency), reduction in infection rate, cost reduction and treatment time. The only drawback of such bacterial nanocellulose is that it cannot be used in the more mobile parts of the body since it is less elastic [9].

Fig. 7. Dressings made with bacterial cellulose that is imposed on burned tissue [9]

Surgical implants – can be used as a tracheotomy tube in reconstructive surgery, like artificial heart valves, like blood vessels in the form of tubes or neurotubes in the regeneration of nerves. Earlier studies have shown that bacterial cellulose is covered with epithelial tissue, due to this it is specific to the organ in which it is implanted [10].

These qualities are very important for bio-implants in the circulatory system, where inflammation is responsible for degenerative changes, and the ability to cover the body's own tissues can lead to insignificant thrombogenicity of the effect (fig. 8).

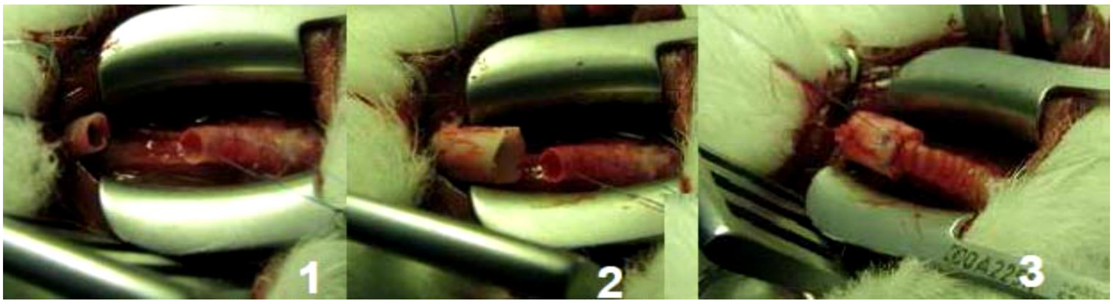


Fig. 8. The reconstruction project of tracheotomy tube [10]

The peculiar nanofibrillar structure of bacterial cellulose properly represents a suitable macromolecular support for the inclusion of drugs, that is, as a carrier of drugs. Early studies have documented the ability of the biocellulose membrane to modulate the release and bioavailability of model drugs for administration, hence such a membrane is proposed as a support for transdermal drug delivery. A capable biocellulose membrane modulates the release of drugs to reduce the number of applications. Membrane flexibility provided by glycerol allows it to be used in more mobile parts of the body. Membranes can also be cut into desired shapes and sizes, corresponding to the target area [11, 12].

To form an immune response, the body is affected by the microflora of the gastrointestinal tract. One of the ways to maintain is the use of prebiotics. Prebiotics - with a systematic use provide an optimization of the micro-ecological status of the human body due to selective stimulation of growth and biological activity of the normal microflora of the digestive tract. Prebiotics are soluble and insoluble dietary fibers. The main representative of insoluble fiber is cellulose. Soluble include polysaccharides, whose products have been used for many years in the food industry as food additives with technological functions of thickeners, stabilizers, gellants [12].

In the human digestive tract, cellulose stimulates the activity of the intestine, strengthening its peristalsis, normalizes the activity of the intestinal microflora, sorbs sterols, prevents their absorption, and promotes the release of cholesterol.

Because biocellulose has a large absorption capacity, it can be used in dietetics as a carrier of additives for a balanced diet. The dietary properties of biocellulose are higher in this respect than pure plant cellulose.

USING OF BACTERIAL CELLULOSE IN COSMETOLOGY

In addition to the medical application of the membrane of bacterial cellulose, scientists have studied its cosmetic application. It is reported that this facial mask, used for 5 minutes, contributed to the increase in skin tightness. This effect is due to the water content of the mask, which increased the absorption of water by the skin. The mask also adheres well to the skin and has no sharp odors [13].

After the first use of this mask, the skin becomes more radiant. After four weeks of use, wrinkles and fine lines of wrinkles are reduced. It has been clinically proven that the biocellulose mask helps to increase the hydration of the skin. The interlocking high-absorbent fibers of bacterial cellulose form a three-dimensional "material", allowing the beneficial ingredients to penetrate deeply into the skin. Since the biocellulose adheres tightly to the skin of the face, while maintaining close contact with the complex of useful ingredients for 20-30 minutes of use, this contributes to a deeper penetration of the active components into the skin [14, 15].

USING OF BACTERIAL CELLULOSE IN THE TEXTILE INDUSTRY

Bacterial cellulose fibers are very pure, 10 nm in diameter and about 0.5 μm. Fibers are very rigid and tensile-resistant, highly porous and numerous nanofibrillar structure. Due to these properties, bacterial cellulose is used in the textile industry (fig. 9) [16, 17].

Fig. 9. Clothing and footwear made of bacterial cellulose [16]

Suzanne Lee, who is working on the Bio-Couture project, recently talked about her work and how she grows and makes clothes from the Kombucha culture. The project, called Bio-Couture, explores the use of bacterial cellulose grown in the laboratory for the production of clothing. The group states that "our ultimate goal is to literally grow a dress in a vat with a liquid ...". In recent years, the Bio-couture project team has tested this incredible bacterial cellulose material, giving it various shapes, such as shoes and body shape. They also developed several prototypes of shirts and jackets [18].

USING OF BACTERIAL CELLULOSE IN THE PAPER INDUSTRY

Bacterial cellulose due to its high purity and structure of microfibrils can be used for an electronic paper substrate. Microbial cellulose by wet synthesis is applied to sheets with a thickness of about 100 microns. In paper production, bacterial cellulose is used as an ultra-strong thin fiber in the form of a mesh net (fig. 10).

Bacterial cellulose is compatible with plant cellulose and it can be grown on a plant fiber network, so biocellulose will be an excellent candidate for strengthening damaged papers. In an early study, the scientist cultivated a producer of bacterial cellulose, namely *K. sucrofermentans*, on the surface of the paper. After 7 days of cultivation, the producer deposits a thin layer (about 10 μm) of bacterial cellulose on the surface of the paper. The structure of bacterial cellulose is more compact and makes the surface of the paper hydrophobic.

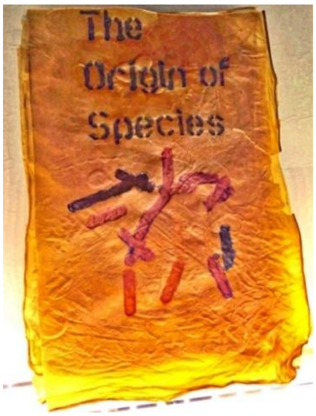


Fig. 10. Paper produced with bacterial cellulose [19]

Paper made from wood has a negative impact on the environment, contributes to the disappearance of large forests, etc. Bacteria also offer an alternative, more sustainable ways of making paper.

In addition, everyone knows the problem with polyethylene. Throughout the world, the plastic bag has become part of the service of all outlets. Moreover, each of us, using a free package, contributes to the pollution of the eco-environment. It is estimated that the lifetime of such a package on average no more than 20 minutes, and it decomposes for more than 100 years. In the environment, ejected packets persist for a long time and are not biodegradable. Thus, they form a stable pollution [19].

Bio packets are packages based on biologically degradable raw materials of plant origin. Depending on the chosen composition, they can have a different service life (on average, from 3 months to 1 year) and a different decomposition period (from 3 months to 3 years). Bacterial biocellulose is an ecologically clean and biodegradable product (fig. 11).

Fig. 11. Biodegradable package obtained from bacterial cellulose [19]

BIOCELLULOSE AND CEMENT

Hydraulic cement with hydrated-hydrolytic hardening and consisting of calcium silicates and calcium aluminate is called silicate cement. As part of the existing calcium silicate affects the mechanical properties, and calcium aluminate controls the tuning time. Cement with such a composition because of long-term stability in the oral cavity is used in dentistry. Binders based on calcium silicates are widely used as a root filling material, that is, as a protective material for revascularization of the pulp or for reducing the permeability of dentin [20].

In earlier studies, composite materials with inorganic or organic substances are reported. Most often silicate cement is indicated in combination with natural fibers, cellulose is one of the most widely used for use. Bacterial cellulose is a natural biopolymer, which is produced with the help of various bacteria, thanks to its physicochemical, mechanical and biological properties, this biopolymer is intensively studied and widely used.

Bacterial cellulose is used to develop organic or hybrid composites. Many researchers have reported that bacterial cellulose is also used as a promising template in the synthesis of nanostructured artifacts. Bacterial cellulose produced by the strain of *Komagataeibacter xylinus* is converted into a powder by means of the lyophilization and grinding procedure, and then it is integrated into the fiber-cement composite materials. The presence of biocellulose nanocrystals in the cement composition accelerates the process of cement hardening. Due to this quality, silicate cement is better than conventional cement [20, 21].

NANOCOMPOSITE MATERIALS BASED ON BACTERIAL CELLULOSE

Cellulose is considered the most widespread polymer on the planet, and it has a great potential as a nanomaterial, which is explained by its renewability and nanofibrillar structure, multifunctionality and the ability to self-organize into a clear architecture.

Nanocellulose (NC) is a new class of cellulose derivatives and is characterized by high crystallinity, highly developed surface, the high degree of dispersity, the ability to decompose under the action of microorganisms [22, 23]. In view of this, NC can be used as a high-quality filler for polymers, a constituent part of materials decomposed by microorganisms, a paper additive, a thickener of dispersions, etc.

NC can serve as the basis for creating nanocomposite materials; in this case, it can be used as a matrix or as a filler. In the first case, nanocomposite systems based on cellulose-containing matrices are formed with the formation of them of nanoparticles and nanostructures of a matrix polymer and a second polymeric or low molecular weight component. In the second case, composite materials are obtained, in which the nanocrystalline material is used as a nanofiller.

Thus, based on the studies carried out, it has been shown that it is possible to obtain new nanocomposite materials based on nanocellulose using it as a matrix and filler, and some physicochemical indices of materials have been studied.

In the field of nanotechnology, the development of biohybrid materials is a new and interdisciplinary field of research. Biohybrid materials, as the name says, consists of several objects: an inorganic nanoobject and a biodegradable material. Bacterial cellulose is used as a template for producing biohybrid inorganic/organic nanocomposites that collects the best properties of biocellulose with properties exhibited by inorganic nanoparticles, such as optical, luminescent, magnetic, photorefractive and photochromic properties [24].

The magnetic nanoparticles serve as a neuronic component in the biohybrid. Magnetic biocellulose nanohybrids possess unique properties, such as magnetic paper for counterfeiting, loudspeakers, magnetically sensitive drive devices, flexible materials for data storage, liquidation of toxic waste, etc.

Cellulose nanocrystals are based on cellulose nanoparticles, which can be extracted by acid hydrolysis from a wide range of materials, namely from natural material (annual plants, trees, algae, and bacteria).

These rod-shaped particles have a unique combination of characteristics: axial stiffness, high tensile strength, low coefficient of thermal expansion, high heat resistance and low density.

These unique properties and characteristics lead to new possibilities in comparison with the traditional methods of obtaining cellulose. Thanks to this, new composites are being developed that can take advantage of them. Nanoparticles made with bacterial cellulose have a low ecological hazard to health, by their nature are renewable, stable and neutral with respect to carbon, as sources from which they are extracted and can be processed on an industrial scale at low cost.

Several years ago, the world's first membrane converter was developed in Sony's headphones. Bacterial cellulose is grown by special producers of biocellulose and processed, in order to be suitable for production. The result is a material ideally suited for speakers that are roughly as rigid as aluminum, but rather light enough to minimize distortion (fig. 12) [24].

Fig. 12. Biocellulose as membrane transducer in Sony headphones [26]

In much the same way that glucometers and pregnancy tests have revolutionized in-home diagnostic testing, researchers have identified a new biosensing platform that could be used to remotely detect and determine treatment options for HIV, *E-coli, Staphylococcus aureus* and other bacteria. Using this technology, they also have developed a phone app that could detect bacteria and disease in the blood using images from a cellphone that could easily be analyzed from anywhere in the world.

Thin, lightweight and flexible materials developed by researchers at Florida Atlantic University, Stanford University, and Harvard University, integrate cellulose paper and flexible polyester films as new diagnostic tools to detect bioagents in whole blood, serum and peritoneal fluid (fig. 13).

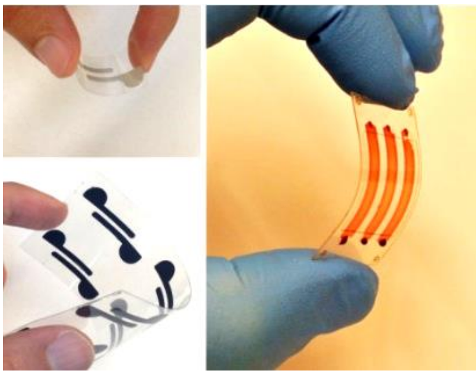


Fig. 13. Thin, lightweight and flexible materials [26]

Researchers are considering the limitations of current paper and flexible material platforms and explain how they integrated cellulose paper and flexible polyester films as new diagnostic tools for detecting bioagents in whole blood, serum and abdominal fluid. They used three different paper and flexible platforms based on materials included in electrical and optical measurement methods. They were able to demonstrate how these new materials can be widely applied to various parameters, including medical diagnostic and biological laboratories.

Using paper and flexible substrates as materials for biosensors, Asgar, and his colleagues have identified a new fast and cost-effective way of diagnosing diseases and monitoring treatment at points of care. They were able to show how their new platforms are uniquely able to isolate and detect multiple biotrates selectively, sensitively and repeatedly from different biological media using antibodies [26].

Microbial-membrane speaker, microphone, and a drum is a unique biomechatronic device, with the main part made of microbial cellulose, grown in a bioreactor with a help of *Komagataeibacter xylinus* bacteria.

As a growing, the medium experimental substrate was used. The author himself designed it and it gives fast material growth rate – production of the membrane.

After growing membrane material, it was incorporated into the frame and treated with substances that enhance its strength and surface tension. A piezoelectric element was integrated into the membrane, which converts mechanical power into electricity (fig. 14) [27].

Fig. 14. Microbial-membrane speaker, microphone and a drum by Gjino Šutić aka Biotweaker [27]

The entire unit works in two ways:

1. As an electrical audio input device -drum or a microphone, where the membrane acts as a collector and a physical vibration amplifier (sound or touch) that is transferred to the piezoelectric sensor that converts these vibrations into the electronic signal that can be reproduced, processed or recorded.

2. As an electrical audio output unit – the speaker, which translates sound in the form of electricity via piezoelectric components into a mechanical force that causes the membrane to vibrate. The membrane vibrates, makes sounds and physically amplifies them [27].

Innovations associated with this device:

– The possibility of growing a microphone, speakers or drum, with easily replaceable parts;

– The ability to completely design and grow this device in all sizes and various shapes.

USING OF BACTERIAL CELLULOSE IN BIOTECHNOLOGY

To promote production in our days, it is necessary to use modern technologies. One direction of modern technology in biotechnology is the immobilization of cells and enzymes. To this end, in recent years there has been an interest in the use of cellulose biomaterials in bioprocessing technology. Pure bacterial cellulose differs from plant cellulose with its unique properties and attracts producers as a new functional biomaterial.

Bacterial cellulose was used in the experiments of Wu and Lia as an immobilizing material and successfully immobilized glucoamylase. In the immobilized state, the enzyme maintained its stability at lower temperatures and pH [28].

Other researchers used bacterial cellulose as an immobilizing material for yeast cells and in a further such composition was used for repeated periodic fermentation for winemaking. Immobilized yeast was economically effective for the process since the consumption of inoculum preparation was reduced so that the yeast was recovered by a simple separation at the end of the fermentation [29].

Bacterial cellulose is tolerant to chemical, thermal and mechanical effects, hydrophilic and has sufficient porosity. In the production of ethanol, two materials were used as an immobilizer or a substrate for yeast: bacterial cellulose and calcium alginate. As a result, according to ethanol producers, yeast immobilized on bacterial cellulose was more effective than immobilized on a matrix with calcium alginate.

Composites based on bacterial cellulose are also used for the synthesis of various enzymes. The bacterium *Corynebacterium glutamicum* was immobilized on bacterial cellulose and was used for the synthesis of L-lysine. Such immobilized cells were used eight times for re-fermentation. At the last fermentation, the yield of the final product was 95%. Stability and survival of cells in the immobilized state was 80% in sterile water (pH 7) stored at 40°C for 30 days.

Also, bacterial cellulose has been used to immobilize enzymes such as peroxidase, glucose oxidase, and lactase. All studies prove that beads or cubes of bacterial cellulose have the potential to use immobilization of enzymes and cells to improve the quality, yield, and stability of the final product [29, 30].

USING OF BACTERIAL CELLULOSE IN ECOLOGY

The bacterial pulp is predicting a promising future in the field of environmental protection for wastewater treatment. Biosynthesis of bacterial cellulose is ecologically flawless and can be carried out using cheap sources of carbon, for example, semi-waste of various manufactures containing monosugars. The filter made of bacterial cellulose is highly porous and elastic. Bacterial cellulose in complex wastewater treatment is used for the first mechanical treatment as a wastewater filter [31].

USING BACTERIAL CELLULOSE IN THE FOOD INDUSTRY

Bacterial cellulose is widely used in various areas of the food industry. It is added to chewing gum and used in the form of gelatinous translucent food product prepared by fermentation of coconut water, which is converted to gelling form by microbial cellulose producing *Komagataeibacter xylinum*. It is also used as a thickener to maintain the viscosity in food and as a stabilizing agent.

Due to its texture and fiber content, it has been added to many food products as dietary fiber. A specific example is Cellulon®, which is a filler used as a food ingredient to act as a thickener, texturizer and/or a calorie reducer. Microbial cellulose has also been used as an additive in diet drinks in Japan since 1992, in particular, in kombucha, a healthy drink based on tea.

Bacterial cellulose is also actively added to food in the Philippines, where it is the main component of the popular dessert - pudding, and jelly with fruit pulp. The bacterium *Komagataeibacter xylinum* is a part of the culture of symbiotic microorganisms, which is called a tea fungus. This product of the vital activity of a multitude of microscopic fungi and bacteria is a thick layered mucous membrane floating on the surface of a liquid nutrient medium. A lot of medicinal and nutritional properties are attributed to the tea mushroom, which indicates its potential for food production. In addition, in the food industry, bacterial cellulose is used to produce "Nata-de-Coco", sweets [32].

Dietary fiber is a large group of substances of different chemical nature, including fiber (cellulose), hemicellulose, gum (gums), pectins, starch and non-carbohydrate lignin. In its pure form, these substances can be used as food additives. In the diet of an adult human, the proportion of all carbohydrates is divided as follows: 70-75% starch, 10% dietary fiber and the remaining 20% simple sugars.

For an adult, the daily norm of dietary fiber in the composition of products is 20 g, of which soluble: pectins, gums, alginates, gum arabic, arabinogalactan, carrageenans, agar-agar, etc. - 2 g per day. Insoluble: cellulose, hemicellulose, lignin, etc. - 20 g per day. The natural pulp is modified and depolymerized mechanically or chemically and can be further used as a food additive [33, 34].

The presence of a β-glucosidase bond in the chemical composition leads to the formation of linear molecules with crystalline zones. Due to this structure, the fibers acquire high mechanical strength and inertness to most solvents and reagents.

Cellulose nutritional supplements in the gastrointestinal tract are not degraded and excreted unchanged, so they are harmless to humans. The daily rate of all cellulose derivatives is 0-25 mg/kg body weight.

As a food additive, cellulose is used in two modifications:

1. Macrocrystalline cellulose is partially hydrolyzed by amorphous sections in acid, more accessible for attack by reagents, ground and differs by truncated molecules;
2. Powdered cellulose - is isolated from plant raw materials, like wood or cotton, then it is purified from hemicelluloses and lignin, the cleansing ground is crushed.

Chemical modification of cellulose molecules leads to changes in the properties of cellulose and changes its function in the digestive system.

Due to the fiber, the time spent on food in the gastrointestinal tract is shortened. When the stool mass is retained for a long time in the large intestine, this results in the accumulation and absorption of carcinogenic compounds, because of such carcinogenic compounds, the probability of swelling is not only not only in the intestinal tract but also in other human organs. Therefore, cellulose helps to remove toxins and toxins from the body. Fiber also slows down the access of digestive enzymes to carbohydrates. Due to this slow process, the organism slowly absorbs mono and disaccharides in the intestine. Accordingly, the body normalizes the glucose content and the synthesis of insulin, which stimulates the formation of fats [34].

Fiber also retains water in the intestines, and it is important in the prevention of constipation, hemorrhoids and helps to ensure a sense of satiety.

In addition, cellulose is considered the main source of energy for microorganisms of the intestine. Anaerobic, lactic and spore bacteria, *E. coli*, streptococci and other microorganisms that are found in the large intestine contribute to the decomposition of the remains of undigested food. Enzymes that secrete bacteria split up to 40% of glucose.

In an early study, the administration of different concentrations of bacterial cellulose in the form of a powder in minced meat was evaluated. The results of model samples on technological properties showed that when large doses of bacterial cellulose are introduced, the pH increases and the mass fraction of moisture in the object increases. Among all the concentrations, it was optimal to inject no more than 1.0% of the bacterial cellulose powder, which leads to an increase in the water-retaining capacity of the product and an improvement in the qualitative characteristics of the raw material.

Organoleptic indicators were assessed on a 5-point scale. The evaluation sample containing 1.0% bacterial cellulose powder has better structure and higher organoleptic properties compared with products containing vegetable cellulose, and control samples: gamma taste, flavor, juiciness.

A new direction in the food industry is veggie meat. Vegetarian meat is made with bacterial cellulose in combination with an extract of Monascus, obtained from the natural pigmented mold. Such a composition stably retains its color and tastes very much like natural meat. Vegetarian meat reduces cholesterol, this is due to the bacterial cellulose present in the meat. Because of non-animal origin, this meat can be a suitable substitute for animal products.

The scientists also studied the use of bacterial cellulose as a potential gelling, thickening, suspending and stabilizing agent in the food industry. Bacterial cellulose is also used as a thermostable suspending agent and is added as a filler to strengthen brittle food hydrogels to improve the value of pasty products. Adding bacterial cellulose to chocolate drinks prevents the precipitation of cocoa, as the mesh from the bacterial cell sticks to it [35].

Food products containing bacterial cellulose are kept moist during the minimum storage period. For example, ice cream with bacterial cellulose maintains its shape at least 60 minutes after its removal from the freezer. Relying on all studies, bacterial cellulose can be widely used in processed foods to improve stability over a wide range of temperatures, pH, and freeze-thaw environments.

CONCLUSION

Bacterial cellulose is considered a universal material of the future. Throughout the world, it is used in surgery, cooking, industry, and fashion designers create amazing outfits from bacterial tissues.

Bacterial cellulose has advantages over its plant analog. Microbial cellulose is capable of synthesizing the genera *Agrobacterium, Achromobacter, Aerobacter, Komagataeibacter, Enterobacter, Sarcina, Rhizobium, Salmonella, Alcaligenes,* and *Mycodema*.

Bacterial cellulose forms a strong gel film of crystalline microfibrils and is characterized by increased elasticity and absence of impurities of hemicelluloses and lignin, which remain even after the most thorough purification of plant material. In addition, considering how many forests are cut down to obtain cellulose, the bacterium has the advantage that it is environmentally friendly and environmentally friendly. The bacterial cellulose architecture created by crystalline microfibrils helps to keep the amount of water that is inaccessible to plant cellulose. If gelatine is added to the biosynthesis of biocellulose, a dense and uniform film is formed with improved optical clarity and increased hygroscopicity.

To date, extracellular bacterial cellulose is used in the high-tech industry to produce new materials and nanocomposites, such as diaphragms in speakers and headphones, and as a storage membrane for a variety of substances in electronics. Microbial cellulose has been recognized in the paper industry and in the manufacture of new packaging materials. A promising future in the field of environmental protection for wastewater treatment is predicted for her. Biosynthesis of bacterial cellulose is ecologically flawless and can be carried out using cheap sources of carbon, for example, semi-waste of various manufactures containing monosugars. Due to its biocompatibility, bacterial cellulose also recently attracted a large amount of attention to biomedical applications.

For example, bacterial cellulose is successfully used as an artificial skin for burns or as a means for wound healing.

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