Bacterial Cellulose: Emerging Sustainable Resource With Diverse Application

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Abstract

In last few years, the high demand for natural biopolymers for numerous industrial usages has fascinated scientists in the production of extracellular polymers from microorganisms. Bacterial cellulose is one such polymeric substance with distinctive characteristic such as biodegradability and nontoxic compound in nature. Bacterial cellulose (BC) is a remarkably fine and nano-fibrillar substance with a distinctive combination of characteristics. These include a high level of crystallinity (ranging from 84% to 89%), a polymerization degree, a substantial surface area, great flexibility, strong tensile strength, and a high capacity to retain water, among others. An appealing aspect of BC is its lack of impurities like polysaccharides and waxes within its structure. This biopolymer, known as bio-cellulose, holds significant value in the production of food, textiles, medicine, and agriculture due to its exceptional properties. In this review article, we present the most recent findings regarding bio-cellulose, building upon previous research efforts aimed at enhancing bio-cellulose production and exploring its potential applications across various fields of activity.

Keywords: Biocellulose, Nano-fibre, Biopolymer.

INTRODUCTION

Cellulose, a naturally-occurring biopolymer, is widely prevalent on our planet. It is comprised of glucose polymer chains connected by β-1-4–glycosidic linkages and exists in different lengths, forming a diverse range of polymerizations. Its chemical composition defines its characteristics. [3]. After its discovery in 1838, cellulose is at the core of industry because of the significance of renewable and environmentally friendly materials and chemical feed stocks [4]. It is a virtually inexhaustible raw material and a key source for biomass production and bio-refineries to produce sustainable materials for industrial applications Although it is isolated and/or produced from different sources, plants and bacterial species are the main source for cellulose synthesis. Nonetheless, the process of improving plant cellulose usually requires intense and aggressive techniques that aim to eliminate substances other than cellulose, such as lignin and hemi-cellulose. There exists an alternative source of cellulose known as bacterial cellulose (referred to as BC hereafter), which does not require any chemical or mechanical refining. BC has been developed as a substitute for plant cellulose. Cellulose from bacteria (BC) was discovered much later than plant cellulose, however it has become a very good alternative to plant one due to its simple and environmentally sensitive extraction conditions compared to extraction of it from plants [5]. The molecular formula of cellulose obtained from plant and Bacteria is the same (C6H10O5)n , despite of the fact that physical and chemical properties of bacterial cellulose are unique. BC possesses a unique three dimensional fibrous porous structure and the multifunctional properties as high purity and high degree of crystallinity (with values of 60-90%), high water absorbing capacity(close to 100 times their own weight), mechanical strength, long fiber length, and nanoscale fibril dimensions make BC more attractive bacterial polymers [6]. The biotransformation of natural unexplored resources to a bio-based green economy requires a invention of materials that are changeable into ameliorated items. In this specific situation, green biotechnology could give an imperative answer for this risky issue for both bio-based green economy improvement and a scope of significant worth added results of interests. The present review article highlights the potential of utilizing microbial-based BC and its composite materials, as a sustainable item for generation of ecofriendly, renewable, and tenable products.

STRUCTURE OF BACTERIAL CELLULOSE

Biocellulose exists as a fundamental fibril structure that comprises of β-1→4 glucan chain having atomic number (C6H10O5)n. The glucan chains are held together by between and intra-hydrogen holding [11] (Fig. 1). Microfibrils of BC were first portrayed by Muhlethalerin 1949 and around multiple times more modest than plant cellulose. The BC fibrous structure is composed of three-dimensional microfibers that are collectively organised, leading to the production of a hydrogel sheet with a large surface area and perforations. Acetobacter xylinum produces cellulose I (strip like polymer) and cellulose II as depicted in Fig. 2 [12]. During the union cycle, proto-fibrils of glucose chain are emitted through microorganism’s cell divider and total together shaping nano-fibrils cellulose strips. These strips build the web molded organization structure of BC with profoundly permeable grid [9]. The cellulose shaped has plentiful surface of hydroxyl bunches that clarifying it as hydrophilicity, biodegradability, and substance adjusting limit [13]. Further system of BC amalgamation was unmistakably clarified by Chawla et al. (2009).

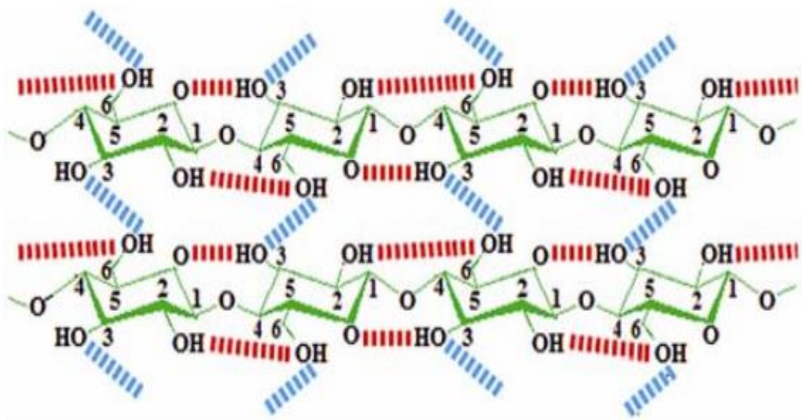

Fig 1: Stucture of celullose

COMPOSITE OF BACTERIAL CELLULOSE

Biocellulose has been applied in diversified fields, for example, wound dressing, vein recovery, and paper rebuilding [14]. Albeit BC has special properties, there is constraint that confines its applications, for example, absence of antibacterial properties, optical straightforwardness, and stress bearing capacity. To defeat these constraints, BC composite has been presented which comprise of a lattice and support materials. BC claims a permeable nature plan of strands. It goes about as framework for lodging an assortment of particles from various support materials. The moored support materials give an extra property to BC that confer its tendency organic and physiochemical properties [15]. BC might be used as a matrix and as a support material. In situ and ex situ processes have been used to mix various BC composites. The in situ method involves incorporating reinforcement elements into the polymer during the curing process, while the ex situ method involves dousing BC in reinforcement agents beforehand. [16].

Physical properties

The strength of the BC films is a key question that has prompted research to increase their mechanical qualities so that they may be used as a wound dressing material. By fusing BC nano-filaments with the PVA polymeric particles, Qiao et al. (2015) were able to frame physical cross-connected composite hydrogels which allowed them to produce a common and uniformly dispersed permeability structure with enhanced mechanical capabilities [17]. N-deacetylated chitin derivative chitosan (Ch) is a unique polysaccharide with outstanding physicochemical qualities such as fume penetrability, antibacterial movement, biocompatibility, and extraordinary film-shaping capability. Damaged chitosan releases N-acetyl-b-D-glucosamine, which stimulates fibroblast proliferation and regulated collagen statement and speeds up wound healing [18].

Biological functions

In spite of the fact that having exceptional physical and compound properties as platforms for wound dressing applications, the native features of BC dressing materials are insufficient to suit the needs of the modern market [19]. These days, it is normal from a dressing material that it has a practical commitment in the mending cycle. The significant intricacies that often emerge incorporate the defilement with entrepreneurial microorganisms and ensuing development of contamination and aggravation and furthermore the development of tumors that add to the development of persistent injuries. Various methodologies have as of late been received to create effective functionalized twisted dressings with adjusted structure [20]. Small atoms, macromolecules, and complex polymers are all included in the mixtures that were shown to have fused into BC during the development or preclinical testing phases. Three principle compound-stacking methodologies have been utilized up until now, post-amalgamation stacking by immersion, by substance alteration of the cleansed BC structure or through hereditary designing methodologies [21]. The decision of the joining procedure relies upon the physicochemical characteristics of the dynamic compound, for example, sub-atomic size, solvency, dependability and working focus, on the kind of biocellulose network, similar to local wet, semidried or even freeze-dried, and furthermore on the bacterial strain utilized as producer. The rate at which the accumulated charge decays over time is crucially affected by the functionalization process. [22].

BIOSYNTHESIS OF CELLULOSE

When everything finishes up, glucose has been used by A. xylinum as a carbon powerhouse for the synthesis of cellulose. Other carbon sources, such as those with 5 or 6 carbons, oligosaccharides and monosaccharides, starch, liquor, and natural acids, have also been taken into account during the production of cellulose [23]. Similar cellulose yields were achieved with fructose and glycerol as with glucose. At high initial glucose concentrations, gluconic acid was accumulated, and cellulose production fell as a percentage of glucose consumed. The diminishing in cellulose yield could be because of some glucose being processed to gluconic corrosive. The pH range of 4.0 to 6.0 is considered to be optimal for the production of cellulose. It was hypothesised that Gluconacetobacter xylinus KU-1 might generate cellulose from D-arabitol [24]. The measure of cellulose from D-arabitol was in excess of 6 fold the amount of as that from D-glucose. In D-arabitol medium, the last pH didn't diminish and D-gluconic corrosive was not identified, this is by all accounts one reason for high profitability of cellulose from D-arabitol. The amount of cellulose produced by using either glucose, galactose, or xylose as a carbon source was calculated by Romano. Lower yields were seen with galactose and xylose, typically as a result of slower growth rates [25]. The microfibrils that can be obtained from xylose are also less common than those that may be obtained from glucose. The examination using gas chromatography revealed that the composition of sugars in the polymers (cellulose and other polymers) that were derived from xylose as a carbon source were nonetheless 80% glucose and 20% other sugars, indicating that there were in fact no variations in the degree of the polymerization process [26]. Times inception of creation was likewise unique for the distinctive carbon sources. The utilization of the less expensive carbon sources may have the option to diminish the creation cost.

Bacterial cellulose yield from sucrose is just a large portion of those from glucose; it is because of the low action of sucrase in A. xylinum. On the off chance that sucrose is effectively hydrolyzed, it will increment bacterial cellulose efficiency [27]. Tajima et al. [28] have prevailing with regards to upgrading bacterial cellulose profitability by the co-development of two unique sorts of Gluconacetobacter xylinus strains. Co-development of Gluconacetobacter xylinus outperformed monocultivation with regard to the bacterial cellulose efficiency. This is due to both glucose and fructose are produced when sucrose is hydrolyzed by sucrase secreted from Gluconacetobacter xylinus NCI 1005. [29]. Different studies used Gluconacetobacter xylinus, the nata life form, which was severed directly from a nata, whereas these researchers used Gluconacetobacter xylinus strains (IFO, ATCC, or NCI). Nata, a popular Filipino dessert, traditionally made in the coconut-growing regions. A strain of Gluconacetobacter xylinus is used to produce the cellulose "gel" or nata, which is subsequently dissolved in coconut water or other natural product juices (such as pineapple, tomato, and so on) that have been sweetened with sucrose [30]. In this particular scenario, fructose produced the highest output, followed by a combination of fructose and lactose. Sucrose and a mix of fructose + lactose additionally gave great yields. These four carbohydrate sources gave significantly preferred yields over any of different sources. Whether glucose is present alone or in a combination with different sugars created lower measures of cellulose. The cellulose yields from sucrose, in spite of the fact that lowers than those from fructose [31].

Production of bacterial cellulose

The current strategies for MC creation are static culture, lowered maturation through circulated air through or fomented development, and the transport bioreactor [32]. Enormous scope, semi-constant and consistent maturation are predominant to satisfy business need. In all cases, the principle objective is to accomplish greatest creation of MC with ideal structure and appropriate properties for the application for which it is proposed. All things considered, a more extensive use of this versatile biopolymer relies upon the functional contemplations, for example, the scale-up capacity and creation costs [33]. G. xylinus has two primary usable amphibolic pathways: the pentose phosphate cycle for the oxidation of sugars and the Krebs cycle for the oxidation of natural acids and related mixes. Thusly, a few investigations have been accounted for that the arrangement of the way of life medium and the aging conditions significantly influence the request structure of cellulose. Static development is a generally basic and broadly utilized strategy for cellulose creation. The medium is put into shallow plate or bottles, vaccinated, and developed for a few days until the cellulose almost fills the plate [34]. G. xylinus produces a thick MC layer, which has a denser surface as an afterthought presented to air, for example fit for creating cellulose as an extracellular item on static media at temperatures somewhere in the range of 25 and 30 °C and pH from 4 to 7 [35]. The conventional static culture speaks to a costly method of MC creation that may thwart its mechanical application since the profitability is low and long development time is required. Thusly, creators have proposed new culture framework as methodology to build the MC efficiency to a reasonable for business applications in basic took care of clump, in bioreactor for a semi-ceaseless creation, in an altered airdrop type bubble segment bioreactor [36].

Modification of Bacterial Cellulose

3D organizing of BC inside a clear, coagulated, joined, nano-stringy organization of straight polysaccharide polymers is shaped at static conditions. In examination with vegetal cellulose sources, BC show noteworthy mechanical properties, for example, adaptability [37] and delicate tissue looking like pressure strain conduct, just as an elevated level of crystallinity and water-holding limit. BC is an unadulterated material where basic cellulose partners, i.e., lignin and hemi-cellulose, are missing. Accordingly, is viewed as a non-cytotoxic, non-genotoxic and profoundly biocompatible material. Nonetheless, BC needs suitable functionalities to trigger the underlying cell connection and authority over the porosity, and it has exceptionally moderate debasement, and so on [38]. To conquer this, BC has been adjusted by substance (alteration of compound structure and functionalities) and physical methods (change in porosity, crystallinity and fiber thickness) by applying versatile in situ and ex situ techniques. In situ adjustments are performed by the variety of culture media, carbon source and expansion of different materials, while ex situ changes are done by synthetic and physical treatment of framed BC [39].

Synthetic change depends on innate compound reactivity because of the presence of hydroxyl gatherings, permitting response at heterogeneous, yet in addition under homogeneous conditions. When contrasted and plant cellulose, the BC was discovered to be more receptive towards cynoethylation and carboxymethylation [40]. The homogeneous response incorporating dissolving of BC with acidic anhydride and further iodination likewise uncovers the most elevated reactivity of BC; yet, such a kind of change demolishes the nanofibrillar structure. Variety of water content inside BC generally impacts its viscoelastic and electrochemical properties. Because of expanded obstruction of BC to electron move, it turns out to be firm at half 80% of water. Such a finding was especially significant in injury dressing applications, where dampness content is an objective. Expansion of water-dissolvable polymers, for example, CMC, methylcellulose (MC), and poly (vinyl liquor) (PVA), was found to impact the water substance of never dried and re-swollen BC. Then again, Bottan et al. [41] presented the guided gathering based biolitography as procedure to change the BC surface geography what is identified with transitory examples and arrangements of human dermal cells, the fibroblasts and keratinocytes.

Enhancement of bacterial cellulose production

Bacterial cellulose creation has been accounted for to be upgraded by the expansion of a modest quantity of a cellulase complex to the way of life stock. Tonouchi et al. [42] analyzed cellulose creation by Gluconacetobacter xylinus utilizing a solitary types of β-1,4-endoglucanase and its dynamic site freak, which actually had cellulose-restricting capacity, however was without the protein action, to recognize the impact of the cellulose-restricting capacity on cellulose creation. They found that the endoglucanase action itself, not the cellulose-restricting capacity, upgraded bacterial cellulose creation [43]. The expansion of modest quantity cellulase doesn't influence the level of polymerization of the bacterial cellulose yet upgrade the creation rate. It has been discovered that the expansion of a business sulfite pulping waste division (named CP powder) into culture medium amazingly improved the proficiency for cellulose creation of Gluconacetobacter xylinus. The CP powder was fractionated by gel filtration with Sephadex G-25 into the high and low sub-atomic divisions (named A and B) and it was explained that the high sub-atomic lignosulfonate portion (A) was fundamental for the astounding yield increment in the cellulose creation of Gluconacetobacter xylinus. Premjet et al. [44] found an easier division technique as follow; the larger measure of CP powder was treated by single ethanol precipitation and isolated into a hasten and non-accelerate. Part C comprises principally of high sub-atomic lignosulfonate practically identical to portion A and shows low sugar substance and solid UV assimilation at 280 nm. Part D, which shows high sugar substance and lower UV retention is practically comparable to division B and is found to comprise essentially of the low atomic weight starches and the low sub-atomic weight lignosulfonate. Part A differs from division C in that the previous contains UV engrossing substance in the D locale. Portion B likewise has a little UV retention in C area [45]. Both part A and B significantly influenced the cellulose creation.

APPLICATION OF BACTERIAL CELLULOSE

Skin

On account of its high faultlessness, hydrophilicity, structure outlining potential, chirality and biocompatibility offers a wide extent of unprecedented applications, for instance as a food cross section (nata de coco), as dietary fiber, as an acoustic or channel layer, as ultra-strength paper and as reticulated fine fiber network with covering, legitimate, thickening and suspending qualities up to now a couple of employments of bacterial cellulose in human and veterinary prescription are known [46]. The high mechanical strength in the wet state, liberal penetrability for liquids and gases and low aggravation of skin indicated that the coagulated film of bacterial cellulose was usable as a phony skin for brief covering of wounds. Biofill® and Gengiflex® are aftereffects of bacterial cellulose with wide applications in medical procedure and dental supplements and genuine elements in the human medical administrations zone. Occurrences of second and third degree of burns-through, ulcers and others could be managed adequately with Biofill® as passing substitute for human skin [47]. The creators revealed the going with great conditions for Biofill® more than 300 therapies: brief alleviation from inconvenience, close hold to the injury bed, reduced post-medical procedure disquiet, diminished illness rate, simplicity of wound assessment (straightforwardness), faster mending, and improved exudates support, and unconstrained partition following reepithelization, and lessened treatment time and expenses [48].

Blood Vessels

The cellulose made by microorganisms could be used for counterfeit veins as it passes on a lower risk of blood bunches than the made materials right now used for avoid undertakings. BC can pass on a lower risk of blood bunches than the designed materials right now being utilized. This infers that the cellulose capacities commendably in contact with the blood and is an amazingly intriguing choice for counterfeit veins. Veritable veins have an internal covering of cells that ensure that the blood doesn't group [49]. This chamber has an internal distance across of 1mm, length of around 5 mm and divider thickness of 0.7 mm. So these limits are sufficient for preliminary microsurgical requirements. A sufficient mechanical strength of the BASYC tubes is one of the essential properties for their utilization in microsurgery [50]. The material ought to contradict both mechanical strains during microsurgical status and looking at and beat of the living body. The nearby bacterial cellulose has mechanical properties, including shape support and tears check, which are superior to various designed materials. In correlation with regular sheets, like polypropylene, polyethylene-terephthalate or cellophane [51].

Consistence botch between the fabricated join together and the encompassing nearby tissue has been represented as an essential issue in outrageous dissatisfaction of the as of now used cardiovascular join replacements [52]. In this manner, making biomaterials that show close mechanical properties as the tissue it is replacing is a huge objective in biomedical devices plan. Polyvinyl alcohol (PVA) is a biocompatible hydrogel with attributes needed for biomedical applications. It might be cross associated by a low temperature warm cycling measure. By using a novel warm getting ready procedure under an applied strain and with the development of a restricted amount of bacterial cellulose (BC) nano fibers, an anisotropic PVA-BC nano composite was made [53]. The weight strain flexible properties of porcine aorta were immovably planned in both the circumferential and the center headings by one sort of anisotropic PVA-BC nano composite inside physiological reach, with improved protection from extra stretch past physiological strains [54].

Medicine

3D organizing of BC inside a clear, coagulated, interlaced, nano-sinewy organization of straight polysaccharide polymers is framed at static conditions. In correlation with vegetal cellulose sources, BC exhibit surprising mechanical properties, for example, adaptability [55] and delicate tissue taking after pressure strain conduct [56], just as a significant level of crystallinity and water-holding limit. BC is an exceptionally unadulterated material where normal cellulose partners, i.e., lignin and hemicellulose, are missing. In that capacity, is considered a non-cytotoxic, non-genotoxic and profoundly biocompatible material. Notwithstanding, BC needs proper functionalities to trigger the underlying cell connection and command over the porosity, and it has moderate debasement, and so forth to defeat this, BC has been altered by compound (modification of synthetic structure and functionalities) and actual methods (change in porosity, crystallinity and fiber thickness) by applying flexible in situ and ex situ techniques. In situ modifications are performed by the variety of culture media, carbon source and expansion of different materials, while ex situ modifications are done by compound and actual treatment of framed BC. Substance modification depend on inherent compound reactivity because of the presence of hydroxyl gatherings, permitting response at heterogeneous, yet in addition under homogeneous conditions [57]. When contrasted and plant cellulose, the BC was discovered to be more receptive towards cynoethylation and carboxymethylation. The homogeneous response incorporating dissolving of BC with acidic anhydride and further iodination likewise uncovers the most elevated reactivity of BC, yet, such a kind of modification pulverizes the nanofibrillar structure.

Drug Delivery

Drugs with more limited half-lives should be overseen in a controlled way, which incorporates a few preferences of the measurements structure, for example, a lessening in portion recurrence, relative security of medication plasma focus, patients' fulfillment and helpful proficiency [58]. BC and other polymeric materials have been comprehensively read for controlled medication conveyance. Production of BC-based nanocomposites to upgrade the controlled medication conveyance is the main technique to advance the medication deferred discharge impacts of BC. In certain investigations, the mix of BC and polyacrylic corrosive (PAA) (BC–PAA) has been set up by polymerization started through electron shaft light utilizing different portions of radiation [59]. The level of expanding in the readied composites was upgraded with an expansion in radiation portion and abatement in ionic strength. Likewise, the composites were touchy to pH and their expanding came to greatest qualities at a pH of 7. These BC–PAA composite hydrogels were inspected as pH-responsive substances for controlled in vitro drug conveyance using different substance of ox-like serum egg whites (BSA) as a model compound [60]. Besides, the medication discharge profiles were controlled utilizing sequentially simulated gastric liquid (SGF) and a simulated intestinal liquid (SIF) without catalysts for 2 h. This is preceded until the most extreme medication discharge is acquired. It was seen that the arrival of medication in SGF was much slower toward the finish of 2 h. Nonetheless, the delivery rate in SIF was altogether higher, however diminished with an expansion in the radiation portion. The different delivering paces of SGF and SIF were credited to the impact of pH on the growing pace of the composites. It was discovered that the pH-responsive conduct of these composites toward drug conveyance was like the characteristic BC films [61].

Mueller et al. [62] concentrated BC as a successful medication conveyance framework for proteins with serum egg whites. It was discovered that the freeze-dried BC materials showed a lower stacking of protein contrasted with the typical BC ones. Different specialists have explored the advancement of BC as a medication conveyance framework by including drug atoms into the BC material, which licenses slow medication discharge [63].

COSMETOLOGY

Notwithstanding the medical application of the layer of bacterial cellulose, researchers have contemplated its restorative application. It is accounted for that this facial veil, utilized for 5 minutes, added to the expansion in skin snugness [64]. This impact is because of the water substance of the veil, which expanded the assimilation of water by the skin. The cover likewise holds fast well to the skin and has no sharp smells. After the main utilization of this veil, the skin turns out to be more brilliant. Following a month of utilization, wrinkles and scarce differences of wrinkles are diminished [65]. It has been clinically demonstrated that the bio-cellulose veil assists with expanding the hydration of the skin. The interlocking high-permeable strands of bacterial cellulose structure a three-dimensional "material", permitting the helpful ingredients to enter profoundly into the skin. Since the bio-cellulose sticks firmly to the skin of the face, while keeping in touch with the complex of valuable ingredients for 20-30 minutes of utilization, this adds to a more profound infiltration of the dynamic parts into the skin [66].

TEXTILE INDUSTRY

Bacterial cellulose strands are unadulterated, 10 nm in width and about 0.5 µm. Strands are unbending and ductile safe, profoundly permeable and various nano-fibrillar structures. Because of these properties, bacterial cellulose is utilized in the material business [67]. Suzanne Lee, who is dealing with the Bio-Couture project, as of late discussed her work and how she develops and makes garments from the Kombucha culture [68]. The task, called Bio-Couture, investigates the utilization of bacterial cellulose filled in the lab for the production of dress. The gathering states that "our definitive objective is to in a real sense grow a dress in a tank with a fluid ...". As of late, the Bio-couture project group has tried this fantastic bacterial cellulose material, giving it different shapes, for example, shoes and body shape. They likewise built up a few models of shirts and coats [69].

CONCLUSION

Taking everything into account, BC might be considered as an expected manufacturer for nano-based materials, for example, composites, movies, froths and gels introducing particular properties. Such materials show up as promising options in contrast to oil based ones, with the benefit of being earth amicable and recyclable [70]. BC presents mechanical and physical exceptional properties that rise up out of its remarkable 3D structure. BC is likewise biodegradable, non-harmful and biocompatible, and is delivered with a special local virtue, which considers its immediate utilization. BC-based materials have been investigated in a variety of potential applications for biomedical purposes, specifically to create improved dressing materials for extreme injury mending. Novel logical works, growing BC-based materials for biomedical applications, have unveiled the capability of these materials, and notwithstanding further examinations on in vivo biocompatibility, a promising future for BC materials is as of now uncovered.

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