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Bacterial Cellulose Acetate: Influence of Degree of Substitution on Structure, Properties and Functional Applications

Suian Moreira Santos Fontes[1*], Tereza Neuma de Castro Dantas[1], Márcia Regina da Silva Pedrini[1,3], Liana Franco Padilha[3*]

[1]*Graduate Program in Chemical Engineering, Federal University of Rio Grande do Norte, Natal, Brazil.*

[2]*Undergraduate Course in Food Engineering, Federal University of Rio Grande do Norte, Natal, Brazil.*

[3]*Food Engineering Department, Federal University of Rio Grande do Norte, Natal, Brazil.*

***Corresponding author**

Suian Moreira Santos Fontes,
Graduate Program in Chemical Engineering, Federal University of Rio Grande do Norte, Natal, Brazil.

Liana Franco Padilha,
Food Engineering Department, Federal University of Rio Grande do Norte, Natal, Brazil.

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Abstract

Bacterial cellulose (BC) is a biopolymer characterized by high purity and a highly organized nanofibrillar structure; however, its insolubility and limited processability restrict its use in advanced polymer systems. Acetylation using acetic anhydride has emerged as an effective chemical modification strategy, enabling the controlled substitution of hydroxyl groups with acetyl groups and leading to the formation of bacterial cellulose acetate (BCA), a material with tunable properties. This review critically discusses the main reaction systems based on acetic anhydride, addressing reaction mechanisms, the influence of catalysts, and operational conditions, as well as their relationship with the degree of substitution (DS). Particular attention is given to the correlations between DS and structural, thermal, and morphological properties, including changes in crystallinity, thermal stability, thermoplastic behavior, and solubility in organic solvents. The implications of these modifications for the formation of films and membranes are also examined, highlighting the role of reaction control in materials engineering for applications in separation processes, functional packaging, and biomedical devices. Finally, current challenges related to precise DS control, reproducibility, and industrial scalability are discussed, which are essential aspects for consolidating BCA as a material of interest in applied polymer engineering.

Keywords: bacterial cellulose, bacterial cellulose acetate, acetylation, degree of substitution, chemical modification, polymeric membranes, processability.

Introduction

The growing demand for sustainable and high-performance polymeric materials has driven the development of macromolecules derived from renewable resources capable of replacing petroleum-based polymers in advanced applications. In this context, bacterial cellulose (BC) has emerged as a promising platform for chemical modification due to its high purity, elevated crystallinity, and highly organized three-dimensional nanofibrillar structure. These characteristics result in superior mechanical performance and structural uniformity when compared with plant-derived cellulose. Thomas et al. (2020) and Römling and Galperin (2015) produced by bacteria of the genus Komagataeibacter, such as Komagataeibacter xylinus, BC is synthesized through the enzymatic polymerization of UDP-glucose, forming a matrix free of lignin and hemicellulose, with high accessibility of hydroxyl groups and significant surface reactivity.

From a polymer engineering perspective, cellulose acetate (CA) is one of the most industrially relevant cellulose derivatives and is widely used in the production of films, fibers, coatings, and membranes. Its physicochemical properties, including glass transition temperature (Tg), crystallinity, solubility, and mechanical performance, are strongly dependent on the degree of substitution (DS), which enables fine tuning of material properties through control of the acetylation reaction (Medronho et al., 2012; Liu et al., 2023). However, the conventional production of CA from plant cellulose often involves aggressive chemical treatments, high solvent consumption, and environmentally demanding processing steps.

In this scenario, the acetylation of bacterial cellulose emerges as a technically attractive strategy for chemical modification, combining the structural uniformity of BC with the processability characteristic of cellulose acetate. The resulting material, known as bacterial cellulose acetate (BCA), partially preserves the nanofibrillar architecture of the original matrix while exhibiting reduced hydrophilicity, thermoplastic behavior, and improved compatibility with organic solvents (Borges et al., 2021; Sannino& Madaghiele,

2021). These modifications significantly expand processing possibilities through techniques such as casting, extrusion, and incorporation into polymeric composites.

Although several studies have reported the synthesis and application of BCA in separation membranes, biomedical devices, and biodegradable films, systematic analyses correlating acetylation parameters, degree of substitution, and functional material performance remain limited. A polymer science-oriented approach emphasizing the structure-property-application relationship and the impact of DS control on thermal, mechanical, and processing properties is still scarce in the literature.

In this review, a critical analysis is conducted of the chemical modification of bacterial cellulose via acetylation as a strategic biopolymer source, emphasizing the control of the degree of substitution of the reaction, characterization methods and their direct implications for the thermal, mechanical, and physicochemical properties of the material. Furthermore, the influence of these parameters on performance in specific applications and the technological challenges associated with scalability and material standardization within the context of sustainable polymer engineering are discussed.

Bacterial Cellulose as a Bioplatform for Chemical Modifications

Bacterial cellulose (BC) is a linear polysaccharide composed of repeating β-D-glucopyranose units linked by β-(1→4) glycosidic bonds, biosynthesized by bacteria of the genus Komagataeibacter through the enzymatic polymerization of UDP-glucose (Thomas et al., 2020). During biosynthesis, the newly formed polymer chains aggregate into highly organized microfibrils, which subsequently assemble into a continuous three-dimensional nanofibrillar network.

From a structural standpoint, BC presents characteristics that significantly differentiate it from plant cellulose. The absence of lignin, hemicellulose, and other plant cell wall constituents results in a material with high chemical purity, elevated crystallinity (typically above 80%), and a homogeneous distribution of nanometric fibrils (Lin et al., 2013; Römling& Galperin, 2015). This organization provides high specific mechanical strength and dimensional stability, as well as a large surface area when compared to conventional cellulose.

From the perspective of polymer science, one of the most relevant aspects of BC is the high accessibility of hydroxyl groups located at the C2, C3, and C6 positions of the anhydroglucose units. Despite the presence of extensive crystalline domains, the nanofibrillar morphology and the absence of a lignocellulosic facilitate reagent diffusion through matrix and the occurrence of chemical modification reactions, particularly in heterogeneous systems.[5] This characteristic makes bacterial cellulose a particularly suitable substrate for esterification reactions, especially acetylation, enabling controlled adjustment of the physicochemical properties of the material.

Furthermore, the highly porous three-dimensional structure of BC contributes to its high water retention capacity and stable mechanical behavior even in the hydrated state, properties that are particularly relevant for biomedical applications and functional membranes (Römling& Galperin, 2015). However, its high hydrophilicity and insolubility in organic solvents limit its thermal processability and compatibility with hydrophobic polymer matrices, reinforcing the need for chemical modification strategies to expand its technological applications.

In this context, BC can be understood as a macromolecular platform in which the controlled modification reaction of hydroxyl groups enables modulation of crystallinity, surface polarity, solubility, and thermal behavior. Among the available routes, acetylation stands out as one of the most effective strategies to reduce the density of intermolecular hydrogen bonds, promote thermoplastic behavior and expand the processing window of the material (Borges et al., 2021).

The acetylation process of bacterial cellulose and the influence of the degree of substitution on the properties of the material are illustrated in Figure 1.

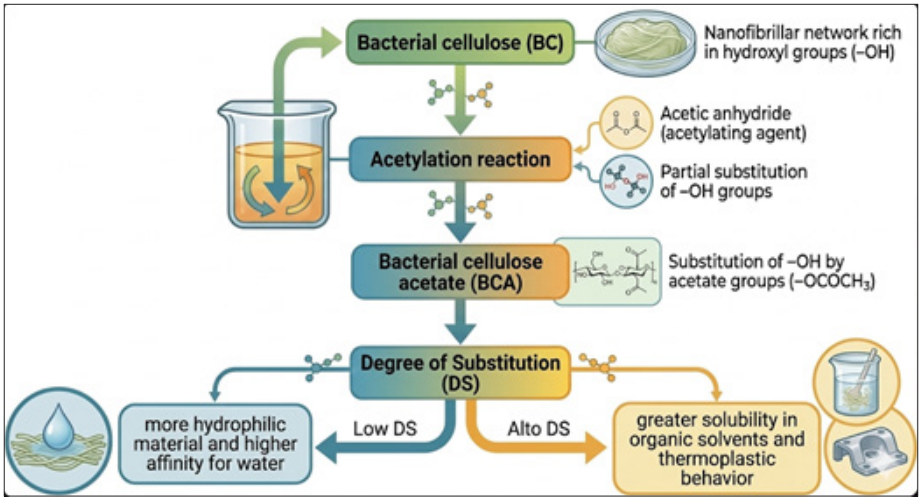

Figure 1: Schematic representation of bacterial cellulose acetylation, illustrating the substitution of hydroxyl groups by acetyl groups and the formation of bacterial cellulose acetate (BCA).

Bacterial Cellulose Acetate: Synthesis, Structural Control, and Characterization

The chemical modification of bacterial cellulose (BC) through acetylation is a widely employed strategy to modulate its polarity, reduce the density of intermolecular hydrogen bonds, and enhance its processability. The introduction of acetyl groups into the anhydroglucose units decreases the hydrophilicity of the polymer, increases its solubility in organic solvents, and improves compatibility with hydrophobic polymer matrices, significantly expanding its technological potential (Borges et al., 2021; Medronho et al., 2012).

The synthesis of bacterial cellulose acetate (BCA) occurs predominantly through a heterogeneous reaction using acetic anhydride as the acetylating agent, often in the presence of acetic acid as the reaction medium and strong acid catalysts such as sulfuric acid or perchloric acid. The reaction mechanism involves protonation of acetic anhydride, increasing its electrophilic character and favoring the nucleophilic attack of hydroxyl groups located at the C2, C3, and C6 positions of the anhydroglucose unit. The relative reactivity of these positions depends on structural accessibility and steric effects intrinsic to the fibrillar network (López-Sánchez et al., 2020; Medronho et al., 2012).

The highly crystalline three-dimensional organization of BC directly influences reagent diffusion and substitution kinetics. Although the absence of lignin and hemicellulose favors greater uniformity in chemical modification when compared to plant cellulose, the high crystallinity can limit the accessibility of hydroxyl groups located in crystalline regions, concentrating acetylation preferentially in amorphous domains. Thus, parameters such as temperature, reaction time, molar ratio between acetic anhydride and anhydroglucose units, catalyst concentration, and moisture content of BC play a decisive role in controlling the degree of substitution (DS) and, consequently, the final properties of the material (Borges et al., 2021; Medronho et al., 2012).

The degree of substitution represents the average number of hydroxyl groups replaced per anhydroglucose unit, with three being the theoretical maximum value. This parameter directly governs the physicochemical properties of BCA, including solubility, crystallinity, glass transition temperature (Tg), thermal stability, and mechanical behavior. In general, intermediate DS values promote solubility in polar organic solvents and good film-forming ability, whereas values approaching the theoretical maximum result in increased hydrophobicity and higher Tg. However, excessively high substitution levels may compromise mechanical properties and reduce biodegradability, an important aspect for sustainable applications (Isogai & Atalla, 1998; Sannino& Madaghiele, 2021).

Structural characterization of BCA requires a multi-technique approach to correlate the extent of chemical modification with the reorganization of the polymer network. Fourier transform infrared spectroscopy (FTIR) confirms the introduction of acetyl groups through the presence of the characteristic carbonyl stretching band in the region of approximately 1740-1750 cm^{-1} and the intensification of bands associated with C-O bonds of the acetyl group, accompanied by a reduction in the broad band corresponding to hydroxyl groups. X-ray diffraction (XRD) reveals a reduction in crystallinity due to disruption of the hydrogen-bond network, while thermal analyses such as thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) allow evaluation of changes in thermal stability and glass transition temperature, which are directly related to DS. Scanning electron microscopy (SEM) reveals modifications in surface morphology, often associated with compaction or partial reorganization of the nanofibrillar network after acetylation (Kongruang, 2021; Jozala et al., 2016).

Functional Properties of Bacterial Cellulose Acetate and Implications for Technological Applications

The introduction of acetyl groups into the structure of bacterial cellulose significantly reduces the density of intermolecular hydrogen bonds, resulting in increased segmental mobility of polymer chains and modulation of the material's polarity. Consequently, bacterial cellulose acetate (BCA) becomes soluble in organic solvents such as acetone and chloroform and exhibits thermoplastic behavior dependent on the degree of substitution (DS), properties that are absent in native BC. This transition from a highly crystalline structural biopolymer to a partially amorphous derivative substantially expands its processability and technological versatility (Borges et al., 2021; López-Sánchez et al., 2020; Medronho et al., 2012).

From a materials engineering perspective, DS acts as a central control variable. As DS increases, a progressive reduction in crystallinity and an increase in glass transition temperature (Tg) are generally observed due to the introduction of bulky acetyl groups that hinder ordered intermolecular rearrangements. This structural modulation directly influences mechanical properties, dimensional stability, and thermal resistance. Several studies report that BCA can exhibit higher thermal degradation temperatures than native BC, particularly at intermediate substitution levels, making it more suitable for processes involving controlled heating, such as film and membrane formation through solvent evaporation (Liu et al., 20223; Medronho et al., 2012).

The reduction in hydrophilicity is one of the most pronounced changes following acetylation. The substitution of hydroxyl groups by acetyl groups decreases water affinity and significantly reduces the water retention capacity typical of native BC. This change affects parameters such as swelling degree, diffusion of polar molecules, and bioadhesivity. In film applications, this transition may result in lower water uptake and greater dimensional stability in humid environments, whereas in biomedical applications, careful adjustment of DS may be required to preserve adequate levels of cellular interaction (Costa et al., 2023; Sannino& Madaghiele, 2021).

X-ray diffraction analysis confirms that acetylation promotes a decrease in the crystallinity index due to disruption of the hydrogen-bond network of cellulose. This structural reduction

tends to increase material flexibility and favor diffusive transport through the polymer matrix, which is relevant for separation and active packaging applications. However, excessive structural disorder may compromise mechanical resistance, once again highlighting the importance of DS control (Kongruang, 2021; López-Sánchez et al., 2020).

Morphological changes are also observed through scanning electron microscopy. While BC presents a continuous and highly organized nanofibrillar network, BCA may exhibit less defined fibrils, increased compaction, or the formation of aggregated domains depending on reaction conditions. These structural changes influence surface roughness, specific area, and interaction with adjacent phases, which are key factors determining performance in composite systems or biological interfaces (Bielecki et al., 2022; Borges et al., 2021).[17,5].

Comparatively, Table 1 summarizes the main structural and functional differences between BC and BCA, highlighting the direct influence of chemical modification on critical engineering properties.

Table 1: Structural and functional comparison between bacterial cellulose (BC) and bacterial cellulose acetate (BCA).

Property	BC	BCA (DS-dependent)	References
Solubility	Insoluble in organic solvents	Soluble in acetone, chloroform, and polar organic solvents	Borges et al., 2021; López-Sánchez et al., 2020
Crystallinity	High (>80%)	Reduced (≈50-70%)	Kongruang, 2021
Degradation temperature (Td)	~250-270 °C	~270-310 °C	Liu et al., 2023
Water retention	Very high (~99%)	Significantly reduced	Costa et al., 2023
Morphology (SEM)	Continuous nanofibrillar network	Less defined fibrils or partially aggregated domains	Bielecki et al., 2022
Processability	Rigid structure, insoluble	Thermoplastic and processable by casting or extrusion	Medronho et al., 2012

Membranes and Separation Processes

The solubility of bacterial cellulose acetate (BCA) in organic solvents and its degree of substitution (DS) - dependent thermoplastic behavior make this material particularly attractive for membrane fabrication through techniques such as solvent casting, phase inversion, and spin coating. Unlike native bacterial cellulose, whose highly crystalline three-dimensional structure limits conformational processing, BCA allows control over the final membrane morphology by adjusting parameters such as polymer concentration, solvent evaporation rate, and coagulation bath composition (Medronho et al., 2012; Borges et al., 2021).

From a structural standpoint, the introduction of acetyl groups reduces the density of intermolecular hydrogen bonds, increasing the amorphous fraction and enhancing segmental mobility. This reorganization directly influences mass transport through the polymer matrix. In dense membranes, diffusion occurs predominantly through the solution-diffusion mechanism, in which permeability is governed by the solubility of the penetrant in the polymer and its diffusivity through the amorphous phase. Therefore, controlled reduction of crystallinity may increase permeability, provided that the mechanical integrity of the membrane is preserved (López-Sánchez et al., 2020; Liu et al., 2023).

The hydrophobicity modulated by DS also plays a central role in performance during aqueous separations. Membranes with intermediate DS values present a balance between resistance to excessive water uptake and maintenance of adequate permeate flux. Very low substitution levels may lead to excessive swelling, whereas very high DS values may reduce affinity toward polar species, affecting selectivity in processes such as ultrafiltration and microfiltration.[15,6]

Another relevant aspect is thermal and chemical stability. BCA exhibits greater resistance to organic solvents and moderate thermal conditions when compared to BC, expanding its potential use in separation systems involving organic solvents or elevated temperatures. This property brings its performance closer to that of commercial cellulose acetates derived from plant cellulose, while maintaining the structural advantages associated with the nanofibrillar architecture and high purity of bacterial cellulose (Borges et al., 2021; Liu et al., 2023).

Additionally, surface morphology and roughness directly influence fouling phenomena and interactions with macromolecules or microorganisms. Changes in surface topology resulting from acetylation and membrane fabrication methods may reduce nonspecific adhesion and improve operational stability in aqueous systems, which is particularly relevant for environmental and biomedical applications (Bielecki et al., 2022; López-Sánchez et al., 2020).

Although studies on BCA membranes remain fewer than those on conventional cellulose acetate membranes, the available results indicate that precise control of DS and processing conditions represents the main strategy for fine-tuning permeability, selectivity, and mechanical resistance. This scenario highlights a promising research field, particularly considering the potential integration of sustainable BC production with controlled chemical modification processes.

Films and Sustainable Packaging

The modulation of polarity and crystallinity promoted by acetylation of bacterial cellulose makes bacterial cellulose acetate (BCA) particularly attractive for the production of films with tunable barrier properties. Its solubility in organic solvents enables the formation of homogeneous films via

solvent casting, allowing control over thickness, density, and surface morphology. Unlike native BC, whose highly hydrated structure hinders the formation of dense and continuous films, BCA enables the formation of compact matrices with lower residual moisture content and improved dimensional stability (Borges et al., 2021; Medronho et al., 2012).

From a packaging engineering perspective, the controlled reduction in hydrophilicity represents a significant functional advantage. Partial substitution of hydroxyl groups by acetyl groups decreases water vapor permeability compared to BC, particularly at intermediate DS values. This property is essential for food packaging applications, where moisture transfer directly influences product shelf life. However, very high substitution levels may increase permeability to nonpolar gases due to the increase in the amorphous fraction, once again highlighting the need for precise DS control (Costa et al., 2023; López-Sánchez et al., 2020).

The reduction in crystallinity after acetylation also affects the mechanical properties of the films. Although the decrease in structural order may reduce the elastic modulus compared to highly crystalline dry BC, the increased segmental mobility enhances flexibility and reduces brittleness, which is desirable in packaging materials. The balance between mechanical strength and flexibility depends not only on DS but also on processing conditions and the presence of plasticizers or polymer blends (Liu et al., 2023; Sannino & Madaghiele,2021). Thermal behavior is another determining factor. The increase in glass transition temperature (Tg) with increasing DS can expand the dimensional stability range under moderate temperature variations, favoring applications involving storage or transportation under different environmental conditions. Furthermore, the higher thermal stability of BCA compared to BC allows processing steps that require controlled heating, improving compatibility with conventional polymer processing technologies (Liu et al., 2023; Medronho et al., 2012).

From an environmental perspective, BCA maintains the advantage of renewable origin and potential biodegradability, although degradation rates depend on the substitution level. High degrees of acetylation tend to reduce susceptibility to hydrolytic and enzymatic degradation, which may increase durability during use but requires careful evaluation when compostability is desired. Thus, structural control of the polymer allows tuning not only of physical properties but also of environmental performance (Sannino& Madaghiele, 2021; Borges et al., 20221).

Although plant-derived cellulose acetate is already widely used in film and fiber applications, BCA offers the additional advantage of high structural purity and nanofibrillar morphology of bacterial origin, which may result in films with more uniform microstructure and potentially improved barrier properties when properly processed. Nevertheless, systematic comparative studies are still required to position BCA competitively against established commercial derivatives.

Biomedical Applications and Advanced Functional Materials

Chemical modification of bacterial cellulose through acetylation also significantly affects its performance in biomedical applications, particularly considering the need for dimensional stability, controlled mechanical resistance, and modulation of interactions with biological fluids. While native BC is highly hydrophilic and exhibits excellent biocompatibility, its high water retention capacity may compromise structural stability in certain clinical applications. The introduction of acetyl groups reduces hydrophilicity and allows improved control over swelling behavior, favoring the development of devices with more predictable functional performance (Römling& Galperin, 2015; Costa et al., 2023).

In wound dressings and tissue engineering scaffolds, BCA offers advantages associated with improved mechanical resistance in the dry state and the possibility of processing into films or membranes with uniform thickness. Partial reduction of intermolecular hydrogen bonding increases segmental mobility, which may enhance the conformability of the material on irregular surfaces of the human body. Furthermore, DS control allows adjustment of properties such as oxygen and water vapor permeability, parameters that are critical for wound healing processes (Sannino& Madaghiele, 2021; Liu et al., 2023).

From a biocompatibility perspective, in vitro studies indicate that acetylation does not significantly compromise cytocompatibility when performed under controlled conditions and with adequate removal of residual reagents. However, excessively high substitution levels may alter cell–material interactions due to the reduction of hydroxyl groups available for protein adsorption, reinforcing the importance of optimizing the degree of modification according to the intended application (Costa et al., 2023).

Another emerging field involves the use of BCA as a substrate for flexible electronic devices and biodegradable biosensors. The combination of higher thermal stability compared to BC, tunable flexibility, and the possibility of surface functionalization favors its integration with conductive materials, metallic nanoparticles, or semiconducting polymers. Its dielectric behavior and ability to form homogeneous films make BCA a promising candidate for biodegradable printed circuit substrates (Zhang et al., 2023).

Additionally, BCA can serve as a matrix for the incorporation of antimicrobial agents, drugs, or biomolecules, forming hybrid systems with controlled release properties. The lower water absorption rate compared to BC may lead to slower and more predictable diffusion profiles, which is desirable in long-term therapeutic systems. However, systematic studies correlating DS, morphology, and release kinetics remain limited in the literature, representing an important research gap (Sannino& Madaghiele, 2021; Liu et al., 2023).

Overall, the application of BCA in biomaterials depends on a delicate balance between chemical functionalization and

preservation of biocompatibility. Therefore, DS engineering emerges once again as a central variable in the rational design of biomedical devices based on this derivative.

Technological Challenges and Future Perspectives

Despite significant progress in recent decades, the development of bacterial cellulose acetate (BCA) still faces technical limitations that hinder its consolidation as a competitive material at the industrial scale. The main challenge lies in the reproducibility and control of the degree of substitution (DS), a parameter that simultaneously governs solubility, crystallinity, mechanical properties, thermal stability, and degradation behavior. Small variations in acetylation conditions-such as BC moisture content, acetic anhydride molar ratio, catalyst type and concentration, and reaction temperature-may result in materials with significantly different properties, complicating standardization and scalability (Borges et al., 2021; Liu et al., 2023).

Another relevant limitation is associated with traditional acetylation routes, which commonly employ strong acid catalysts and potentially toxic solvents. Although these methods exhibit high reaction efficiency, they compromise the environmental sustainability of the process and require rigorous purification steps to remove residual reagents. In this context, strategies based on deep eutectic solvents (DES), milder catalytic systems, and enzymatic approaches have been proposed as alternatives aligned with the principles of green chemistry. However, such methodologies still face limitations related to reaction yield, precise DS control, and economic feasibility (Sirviö et al., 2020; Sannino& Madaghiele, 2021).

The intrinsic structural variability of bacterial cellulose also represents a critical factor. Differences in cultivation methods, substrate type, microbial growth rate, and purification protocols influence the initial crystallinity, nanofibril thickness, and residual moisture content, directly affecting acetylation kinetics. Consequently, the absence of standardized protocols for BC pre-characterization complicates comparisons among studies and reduces interlaboratory reproducibility (Thomas et al., 2020; Römling & Galperin, 2015).

Another important challenge involves preserving the nanofibrillar architecture of bacterial cellulose during chemical modification. Depending on reaction conditions, acetylation may induce structural reorganization of nanofibrils or partial aggregation of the three-dimensional network, affecting properties such as porosity, surface area, and mechanical resistance. Studies indicate that acetylation often initially occurs on the surface of microfibrils, gradually altering the crystalline organization and morphology of the material. Therefore, controlled acetylation strategies have been investigated to promote chemical functionalization without compromising the integrity of the original nanofibrillar structure, particularly in applications requiring high permeability or surface interaction, such as membranes and biomedical supports (Kim et al., 2002; Foresti et al., 2016).

From an application standpoint, systematic studies correlating degree of substitution, morphology, and functional performance under real operating conditions remain scarce, particularly for separation membranes and biomedical devices. Most available studies focus primarily on structural and thermal characterization, while analyses of long-term durability, chemical resistance, accelerated aging, and mechanical cycling behavior remain limited in the literature (Liu et al., 2023; Borges et al., 2021).

Another underexplored aspect concerns life cycle assessment (LCA) and techno-economic evaluation of BCA production. Although the raw material is renewable, the overall sustainability of the process depends on energy efficiency, reagent consumption, and solvent recovery. The absence of such analyses prevents objective comparison with plant-derived cellulose acetates that are already industrially established.

In addition to challenges related to chemical modification, the industrial feasibility of BCA also depends on advances in the biotechnological production of bacterial cellulose itself. Although different cellulose-producing microorganisms exhibit high biosynthetic efficiency, factors such as volumetric productivity, substrate cost, and bioreactor scalability still limit large-scale production. In this context, strategies involving optimization of fermentation conditions, utilization of agro-industrial residues as carbon sources, and development of more efficient cultivation systems are being investigated to make bacterial cellulose production economically viable for industrial applications (Thomas et al., 2020; Römling & Galperin, 2015).

Future directions for BCA research should therefore focus on three main axes:

1. Development of more sustainable and reproducible acetylation routes with precise DS control;
2. Standardization of characterization protocols to enable comparability among studies;
3. Expansion of applied investigations focusing on long-term performance, environmental stability, and regulatory validation.

Another aspect that has recently attracted increasing attention concerns the need to establish quantitative correlations between molecular structure, degree of substitution, and functional performance. Although several studies report DS values and structural characterization of bacterial cellulose acetate, systematic investigations relating these parameters to transport properties, mechanical behavior, and chemical stability under real operating conditions remain limited. Advancing in this direction is essential for consolidating material engineering guidelines based on the structure–processing–property relationship, a principle widely applied in the development of functional polymers and advanced materials (Isogai & Atalla, 1998; Medronho et al., 2012).

Additionally, controlling cellulose crystallinity during the acetylation process remains an important challenge. Depending on the reaction system employed, chemical modification may induce structural transitions or significant

reductions in crystallinity, directly impacting mechanical properties and thermal stability. Recent studies have sought to develop modification systems capable of promoting surface functionalization while preserving the original crystalline structure of cellulose, a strategy considered crucial for maintaining structural performance in advanced polymer material applications (Wang, et al., 2026).

Conclusion

Bacterial cellulose acetate (BCA) emerges as a promising derivative of bacterial cellulose, combining the structural purity of the microbial matrix with the functional versatility provided by acetylation. Controlled modulation of the degree of substitution enables the tuning of key properties such as solubility, thermal stability, crystallinity, and mechanical behavior, significantly expanding the range of applications in films, membranes, and biomaterials.

Although progress in synthesis and characterization has been substantial, challenges remain regarding process reproducibility, industrial scalability, and the development of more sustainable chemical modification routes. The consolidation of BCA as a technological platform will depend on the development of greener modification methodologies, the standardization of characterization protocols, and the expansion of applied studies correlating structure and performance under real operating conditions.

Given the growing interest in renewable high-performance materials, BCA holds strategic potential within the context of sustainable polymer engineering. A deeper understanding of the structure–process–property relationships will be crucial for transitioning this material from an emerging research topic to a competitive technological solution at the industrial scale.

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Conflict of Interest

The authors declare no conflict of interest.

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