

Sustainable Production of Biocellulose using food waste as Fermentation Substrate

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Keywords: Bacterial Cellulose; Sugarcane Bagasse; Utilized Tea; Food Waste Valorization; Renewable Biomass; Hestrin–Schramm Medium; Sustainable Production; Characterization

Received on 25 Feb 2026

Accepted on 20 Mar 2026

Published on 31 Mar 2026

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Abstract

Bacterial cellulose (BC) is a biodegradable and biocompatible biomaterial with distinctive properties, including high crystallinity, mechanical strength, porosity, and water-retention capacity. However, the relatively high cost of conventional culture media remains a major limitation to its large-scale production. This study aimed to investigate the potential of food and agricultural waste as low-cost substrates for bacterial cellulose production and to compare the resulting BC with that produced using standard Hestrin–Schramm (HS) medium. Sugarcane bagasse and utilized tea were evaluated as alternative carbon and nitrogen sources, respectively, using a SCOBY culture as the inoculum. Fermentation was conducted under static conditions at 30 °C, and bacterial cellulose formation was assessed using different substrate combinations and concentrations. The pH and wet weight of the produced BC were measured, while Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), and field-

emission scanning electron microscopy (FE-SEM) were used for characterization. Bacterial cellulose formation was observed with several substrate combinations, with the 1500 mL bagasse-water and utilized-tea medium producing the highest recorded wet weight (55.4854 g), compared with 15.7408 g obtained from the standard HS medium. The pH of the production media after inoculation ranged from 4.0 to 4.5. FTIR spectra of BC produced from bagasse and utilized tea were comparable to those of BC produced using HS medium, indicating similar characteristic functional groups. XRD analysis showed comparable cellulose characteristics between bagasse-derived BC and the standard, while glucose-derived BC showed differences that may be associated with impurities. FE-SEM revealed a densely packed fibrous network with irregularly arranged fibrils in the bagasse-derived BC. Overall, the findings demonstrate the potential of sugarcane bagasse and utilized tea as inexpensive alternative substrates for bacterial cellulose production and food-waste valorization. Further optimization, purification, and scale-up studies are required to establish their industrial feasibility.

Introduction

Cellulose is a biopolymer that has a wide range of industrial applications [1]. This linear homopolysaccharide is composed of β -D-glucopyranose units that are linked by β -1, 4 glycosidic bonds [2]. It is a polysaccharide consisting of 15,000 D- glucose monomers.

Two glucose monomers are joined by β -1, 4 glycosidic bonds [3]. There is a growing interest in the use of bio-cellulose materials in the biomedical sector, especially in areas like tissue engineering, wound healing, and drug delivery. Cellulosic materials are particularly promising due to their physical and biological properties, biocompatibility, biodegradability, and low toxicity [4]. Apart from their use in pulp, paper, pharmaceuticals, and renewable fuel production, they also hold promise in the development of biological implants, scaffolds for tissue engineering, medical implants, drug delivery systems, and wound/burn dressing materials [5].

Plant cell walls possess remarkable strength and can withstand osmotic pressure variations of up to 20 atm between the extracellular and intracellular compartments. Trees and other large plants have cell walls that can bear loads [6]. The primary structural element of plant cell walls is cellulose, which imparts strength and rigidity to plants [7]. Interestingly, on Earth, the yearly production of cellulose amounts to approximately 1.5 trillion tons [8]. Cell wall of the plant consisting of middle lamella, primary cell wall, and plasma membrane. Plant cell walls are multilayered and comprises three parts (middle lamella, primary cell wall, plasma membrane). Middle lamella, the outer cell layer part consists of pectin that helps in cell attachment [9]. The primary cell wall consists of cellulose microfibrils within hemicellulose fibers. Once the primary cell wall stops dividing, it thickens to form a secondary cell wall [10]. BC is composed of ribbon-like cellulose nanofibers, that weave together to form a 3Dreticulated network [11]. The structure of BC has both crystalline and non-crystalline areas, similar to that of plant cellulose, having up to 90% crystallinity [12-13]. Additionally, it exhibits elevated levels of polymerization, mechanical strength, water retention capacity, chemical stability, and adaptability to biological environments [14]. Bacterial cellulose demonstrates environmental friendliness and sustainability. It is biodegradable and has no deleterious or allergic side effects [15]. Structure of Bacterial Cellulose [16]. Notably, *Acetobacter* bacteria synthesize BC rapidly, achieving high productivity within short periods. BC biosynthesis occurs in periplasmic space, where individual molecules are extruded via a self-assembling mechanism to form protofibrils, which then aggregate into ribbon-shaped microfibrils. Recent advancements in culture methods, fermentation techniques, media formulations, and bioreactor designs, such as rotating disc reactors or radial function-based bioreactors with mild shear stress, have facilitated BC production while minimizing damage during cellulose export. Novel strategies involve using culture media comprising sugared wastes supplemented with alcohols or organic acids at concentrations below 0.5% to stimulate cellulose synthesis [17].

The symbiotic culture of bacteria and yeast, known as SCOBY, is composed of a diverse community of bacteria and yeast strains [18]. The most crucial bacteria in SCOBY are Gram-negative species such as *Acetobacter* and *Gluconacetobacter*, which play a vital role in the fermentation process responsible for producing kombucha and bacterial cellulose [19]. In the SCOBY, acetic acid bacteria and yeast work in symbiosis to enhance cellulose production [20]. Yeasts in SCOBY possess invertase enzymes, which break down sucrose into reducing sugars, releasing monosaccharides into the medium. Kombucha, a popular fermented tea drink enjoyed globally, originated in China and later spread to Russia and beyond. Initially, microbiologists categorized Kombucha as a type of lichen because it involves a symbiotic relationship between fungi and acetic acid bacteria (AAB). However, unlike typical lichens, which are symbiotic associations of algae and fungi and rely on light for photosynthesis, Kombucha thrives in darkness [21].

Gluconacetobacter xylinus uses the pentose phosphate cycle and the Krebs cycle to synthesize bacterial cellulose from glucose residues. However, it cannot metabolize glucose anaerobically, so BC synthesis depends on a metabolic pool of hexose phosphate. Hexose phosphate is produced directly through the phosphorylation of exogenous hexose or indirectly through the pentose phosphate pathway and

gluconeogenesis. The conversion of glucose, which is transported from the external environment, involves four bacterial enzymes: glucokinase, the first enzyme which initiates the process by phosphorylating carbon 6 of glucose to yield glucose-6-phosphate. Phosphoglucomutase further catalyzes the isomerization of glucose-6-phosphate to glucose-1-phosphate. While UDPG- pyrophosphorylase is responsible for synthesizing UDP-glucose, which is then polymerized into cellulose-by-cellulose synthase enzyme [22]. SCOBY typically thrives in an acidic environment with a pH range of about 2.5-4.5. This low pH is primarily due to the production of acetic acid and lactic acid during the fermentation process. The acidity of the environment helps create a suitable and protective habitat for the bacteria and yeast within the SCOBY community [23]. Temperature is another critical parameter that influences the adaptation patterns of microorganisms for survival. A temperature range of 25 to 30 °C is optimal to produce BC by certain *Komagataeibacter* species, while the optimum temperature for BC production by *Acetobacter xylinum* is 28 °C [24].

Waste materials pose significant economic and environmental threats to the world. Food waste is a major concern, as food manufacturers and processors generate millions of tons annually, much of which could be prevented or recycled. Approximately one-third of all food produced worldwide is lost or wasted, leading to direct product loss and the discarding of valuable byproducts rich in sugars and other food ingredients by various industries. This not only impacts economies but also creates conditions favorable for microbial growth, posing environmental and health risks. In addition to reducing waste, it's crucial to explore opportunities for recycling and converting waste into valuable products [25]. Globally, there is about 2 billion tons of agricultural waste that accumulates every year. Pakistan is ranked fifth among all sugar-producing countries and in 2022 [26], it produced 88 million tons of sugar cane [27]. Sugarcane bagasse is highly valued by sugar producers as a primary feedstock source for bioenergy and biofuel production due to its rich carbon content [28]. Additionally, it has the potential to be used in the production of bacterial cellulose.

For over a century, there has been considerable interest in developing cost-effective methods for producing BC. The main challenges have been the expense of commonly used culture media and the slow production processes, hindering large-scale industrial production. Various approaches, including novel synthetic methods and the use of different bioreactors, have been explored to improve BC production. Despite some success, achieving economically viable BC production remains elusive. Efforts have focused on using inexpensive and waste sources such as fruit juices, bagasse, molasses, and industrial wastes. While these alternatives can reduce production costs, challenges like purification expenses, environmental concerns, and subpar physiological qualities persist. Finding affordable materials with easy processing methods for high-quality BC production remains a crucial endeavor [29]. This research aimed to synthesize bacterial cellulose using waste materials such as carbon and nitrogen sources. Furthermore, bacterial cellulose production was qualitatively and quantitatively estimated. This work eventually will be helpful to produce a sustainable and cost-effective product and will additionally reduce food waste.

METHODOLOGY

Study Location

The bacterial cellulose production and optimization was done at the Biochemistry lab, Kinnaird College for Women, Lahore. Characterization tests such as Fourier Transform Infrared (FTIR), XRay Diffraction (XRD), and Scanning Electron Microscopy (SEM) were done commercially at Comsats Research Centre, Lahore.

Materials Required

Kombucha SCOBY was purchased from Nature's store (<https://thenaturesstore.com/>). The sugarcane bagasse was obtained from a commercial vendor. Glucose and utilized

tea were obtained from the Biochemistry laboratory and Cafeteria of Kinnaird College for Women, Pakistan.

Preparation of HS Media

Standard HS media was prepared by adding 4g glucose, 1g yeast extract, 1g peptone, 0.3g citric acid, and 0.54g NaHPO₄ in 200 ml of distilled water. The pH was adjusted between 4 to 5 with the addition of HCl. The flask was covered with a cotton plug and aluminum foil. Then, the prepared HS media was autoclaved at 121° C for 120 minutes [30]. SCOBY, a mixture of various bacteria, was added in standard culture media. After every two months, the culture media was sub-cultured for inoculum development and kept in a refrigerator at 4°C.

Subculturing of SCOBY

The cellulose film holding the adherent *Gluconacetobacter Xylinus* cells was kept at -80°C. It was then transferred to liquid HS media to create the inoculum culture. The cells were then statically cultivated for two days at 30°C. The cell's dispersion in the inoculum was then homogenized by giving the statically developed culture a vigorous shake. A 250 mL semi-capped glass vessel filled with 100 mL of each of the various liquid media was Injected with the obtained cell suspension (3 mL), and the vessel was then statically incubated at 30°C for ten days [31].

Production of Bacterial Cellulose (BC)

Bacterial cellulose production was done by using different carbon and nitrogen sources in medium-size plastic containers. The following combinations were used as the medium for bacterial cellulose production by SCOBY.

HS medium as standard.

Bagasse and utilized tea.

Glucose and utilized tea.

Production of BC from Hestrin-Schramm (HS) media

First, the media was prepared by adding carbon and nitrogen sources to water. 800µl SCOBY culture was added in 200 ml HS media and then, pH was checked to be 4.5. The media components were gently stirred and mixed with bacterial culture. Then, the containers were covered with gauze to allow oxygen passage through the media. These containers were placed in an incubator at a temperature of 30 °C for 7-10 days. The bacterial cellulose growth was examined and further processed by washing with distilled water and air dried [30].

Production of BC from Bagasse and utilized tea

Pre-Treatment of sugarcane bagasse

The pulpy fibrous material of sugarcane bagasse after the removal of pith and rind was subjected to a thorough washing process with distilled water. After drying, it weighed about 100g and boiled in a beaker using a Bunsen burner for 1 and half hours. Initially, 1000ml distilled water was added to 100g of bagasse and its volume reduced to the desired concentration. The resulting mixture was then strained with a gauze cloth to obtain the bagasse water. This process ensured that the sugarcane bagasse was properly treated for further use [32].

Bagasse water with NaOH

200ml bagasse water as a carbon source was dissolved with 10g of NaOH and 4g of utilized tea extract was added as the nitrogen source for 200ml setup. 800ul SCOBY was used as the inoculum for bacterial cellulose synthesis [33].

Bagasse water with varying concentration

200ml bagasse water and 4g of utilized tea extract were used as carbon and nitrogen sources for 200ml setup. 800ul SCOBY was used as the inoculum for bacterial cellulose synthesis. 100ml bagasse water and 2g of utilized tea extract were used as the carbon and nitrogen sources for 100ml setup, and distilled water was added to make the volume up to 100 ml. 800ul SCOBY was used as the inoculum for bacterial cellulose synthesis. 300ml bagasse water and 6g of utilized tea extract were used as the carbon and nitrogen sources for 300ml setup. 1200ul SCOBY was used as the inoculum for bacterial cellulose synthesis. 1500ml bagasse water and 30g of utilized tea extract were used as the carbon and nitrogen sources for 1500ml setup. 6000ul SCOBY was used as the inoculum for bacterial cellulose synthesis [32]. All setups were placed in an incubator at a temperature of 30 °C under static conditions.

Production of Bacterial Cellulose from Glucose and Utilized tea

4g of utilized tea extract and 4g of glucose were added in the 200 ml water as nitrogen and carbon sources for a 200ml reaction setup. 800µl SCOBY was added as an inoculum for bacterial cellulose synthesis. The entire fermentation took place under static conditions in an incubator at a temperature of 30 °C. Following 7-14 days, bacterial cellulose growth was examined as per media conditions [31].

Production of Bacterial Cellulose from only Bagasse water

200ml bagasse water as a carbon source and 800ul SCOBY was used as the inoculum for BC synthesis. However, no utilized tea was added as a nitrogen source. The setup was placed in an incubator at a temperature of 30 °C to allow fermentation under static conditions. After 7-14 days, bacterial cellulose growth was examined as per media conditions.

Production of Bacterial Cellulose from only Utilized tea

6g of utilized tea was added as a nitrogen source with no glucose or bagasse added as carbon source for a 300ml setup. 1200ul SCOBY was used as the inoculum for Bacterial Cellulose synthesis. The growth was assessed after 7-14 days of incubation at a temperature of 30 °C under static conditions

pH measurement

The pH of the media was checked with the help of pH strips. pH was checked to allow adjustments in pH to a range of 4 –5 for maximum bacterial cellulose yield.

Washing and Drying of Bacterial Cellulose

After the formation, the layer of bacterial cellulose was first washed with distilled water 3 to 4 times and then it was further washed with 0.1% NaOH to remove all the impurities. After the process of washing, the layer was placed on a plane object and dried in sunlight.

Weight Measurement

Weight of Bacterial cellulose produced from various culture media with different carbon and nitrogen sources was measured by the weighing machine. All setups were placed in an incubator at a constant temperature of 30 °C. k) Washing of Bacterial cellulose to remove impurities. L) Drying of Bacterial cellulose.

Characterization of Bacterial Cellulose**X-Ray Diffraction**

X-ray diffraction is used to identify the crystallinity of products. The cellulose structure is highly ordered, which means it consists of more crystalline and less amorphous features. The balance between crystalline and amorphous areas is known as crystallinity

and is analyzed by using X-ray diffraction (XRD). Crystallinity is the unique property of cellulose which identifies its mechanical properties and affinity for water. In X-ray diffractograms, the peaks of crystalline portions are distinct and sharp, whereas the amorphous portion results in diffuse peaks [34]. X-ray diffraction was performed by a diffractometer (Rigaku, MiniFlex II, Tokyo, Japan) operating at 220V. Bacterial cellulose was homogenized before analysis. The sample was placed in the sample tray where the surface was smoothed. The X-ray diffraction spectra were recorded using diffractometer in steps of 0.02° using Cu K α radiation. Scans were performed at the range of 5-40 in 10 degrees/min.

Fourier Transformed Infrared (FTIR) Spectroscopy

The FTIR-ATR is used to analyze functional groups in the material subjected to investigate biomolecules, polymers, and assess the composition of unknown materials. It works by sending modulated infrared radiation from 10,000 to 100 cm⁻¹ through the sample. The infrared radiation is absorbed at specific frequencies directly related to atom-to-atom vibration bond energy in the molecule. Molecules can only absorb radiation when the bond of energy of the atom is equivalent to the infrared radiation, resulting in the vibration of molecules at different energies. The signal is detected at the detector and presented as a spectrum known as molecular fingerprint. This fingerprint is unique to each molecule and is a tool to identify the chemical structure [35]. Fourier Transformed Infrared (FTIR) Spectroscopy associated with Attenuated Total Reflection

(ATR) mode of bacterial cellulose was performed by using FTIR spectrometer (Nicolet 6700, Thermo Scientific, Waltham, USA). Spectra were recorded at wavelength 4000-650 cm⁻¹, resolution 8cm⁻¹, and number of scans 128 cm⁻¹.

Field Emission Scanning Electron Microscope (FE-SEM)

Field Emission Scanning Electron Microscope (FE-SEM) is an advanced type of SEM that is used for the capturing of microstructure images of the particles, and topographical evidence with a magnification range of 10X to 300, 000X. With FESEM the unlimited depth of field can be observed. It gives a clear image with high resolution and magnification with low accelerating voltages that help in the morphological characterization (shape, size, diameter, range) of objects like nanomaterial, thin film, and polymers. In FESEM, the field emission source liberates the electrons that accelerate in a higher electric field gradient. Then these primary electrons are focused, which are then deflected by the electronic lenses that produce the narrow beam that bombards objects within a high vacuum column. The generated secondary electrons are detected by the detector and produce electrical signals which are amplified and digital images. The Apreo 2 SEM is an optical system that aligns itself and has a Thermo Scientific Align Technology. It automates the fine-tuning process of image with the help of Thermo Scientific FLASF technology that forms a final focus of image by doing the necessary corrections to the lens centering [36]. Surface morphologies of the samples were performed using variable pressure Field Emission Scanning Electron Microscope (FE-SEM) Apreo S from ThermoFischer Scientific Eindhoven, The Netherlands. The sample was dried at 45 C° using hot oven before administering to the FE-SEM for analysis.

RESULTS AND DISCUSSION

Production of Bacterial Cellulose

A fine layer of bacterial cellulose was produced by nitrogen and varied carbon sources. The SCOBY culture mainly consisting of *Gluconacetobacter* bacteria was used for its production. After placing the media in a suitable environment, the Bacterial Cellulose layer formed between 10 to 14 days from different carbon and nitrogen sources as illustrated in Figure 4.1. Results obtained from different culture media employed for

bacterial cellulose production were given in Table 1. The layer was separated from the media and then washed and dried. After drying, bacterial cellulose layers can be used for different purposes in the pharmaceutical, textile, and paper industry.

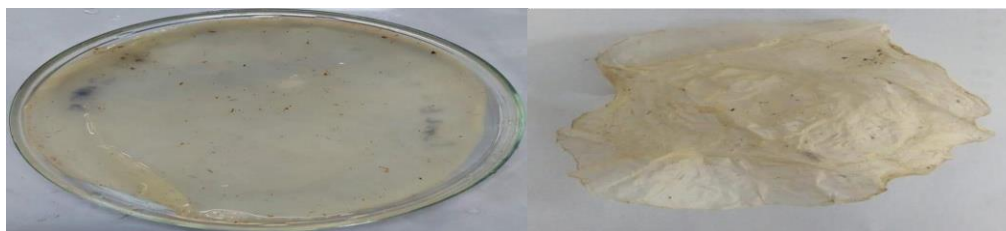


Figure 3.1: a) Bacterial cellulose layer produced b) Dried form of bacterial cellulose.

Production of bacterial cellulose using different sources

Results obtained from various culture media employed for bacterial cellulose production are given in Table 3.1. The Bacterial Cellulose layer was formed between 10 to 14 days using different carbon and nitrogen sources, and it was washed and air dried as shown in Figure 3.1.

Table 3.1: Bacterial cellulose produced using different sources.

Media	Production of Bacterial cellulose
HS Media	A clear prominent layer of bacterial cellulose formed.
Bagasse water with NaOH	No formation of Bacterial Cellulose occurs.
100ml Bagasse, 100ml Distilled water and Utilized Tea	A thin layer of Bacterial cellulose formed.
200ml Bagasse and Utilized Tea	A clear layer of Bacterial cellulose formed.
300ml Bagasse and Utilized Tea	Substantially thicker layer of Bacterial cellulose formed.
1500ml Bagasse and Utilized Tea	A significant clear and denser bacterial cellulose layer formed.
Glucose and Utilized Tea	The prominent layer of Bacterial cellulose layer formed.
Only Bagasse	Little pellicles of bacterial cellulose were formed.
Only Utilized Tea	No formation of Bacterial Cellulose occurs.

Optimization of pH for production of Bacterial cellulose

The optimal pH for bacterial cellulose production by SCOBY is between 4 and 5. The pH adjustments were measured by pH strips to optimize the efficiency of SCOBY and increase Bacterial cellulose yield as illustrated in Figure 3.1. Acidic pH increases the crystallinity and yield of bacterial cellulose, so the pH should not increase above 5.

Table 3.2: pH measurements of different culture mediums before and after the addition of SCOBY

Substrate	pH before the addition of SCOBY	pH after the addition of SCOBY
Standard HS media	6	4.5
100ml Bagasse and utilized tea	5	4
300ml Bagasse and utilized tea	5	4
300ml Bagasse and utilized tea	5	4
Glucose and utilized tea	6	4

Weight Measurement

Wet hydrated weight was measured to quantitatively determine the yield of Bacterial cellulose. It signifies the water retention capability of BC and the efficiency of the production method utilized. Under static conditions, the wet weight of different Bacterial cellulose film was given in Table 3.3.

Table 3.3: Wet weight measurements of Bacterial cellulose produced from different culture mediums.

Substrate	Weight measurement (g)
HS Media	15.7408
200ml (100ml Bagasse water, 100ml Distilled water) and Utilized Tea	2.8459
200ml Bagasse and Utilized Tea	9.2734
300ml Bagasse and Utilized Tea	18.5999
1500ml Bagasse and Utilized Tea	55.4854
Glucose and Utilized Tea	16.0142

Characterization of Bacterial Cellulose

To analyze the various properties of bacterial cellulose including its crystallinity, water holding capacity, and high degree of polymerization, different tests were performed. For the characterization of bacterial cellulose, tests of X-ray Diffraction, FTIR, and Scanning Electron Microscopy were commercially performed.

X-Ray Diffraction

The XRD spectra of the bacterial cellulose membranes utilizing different carbon and nitrogen sources were generated in the form of graphs. The data obtained for bacterial cellulose using natural waste sources was compared with the bacterial cellulose produced using standard HS media.

XRD of BC produced by HS Media, Bagasse, and Glucose

The degree of crystallinity impacts the material's properties such as strength, biodegradability, and interaction with other substances.

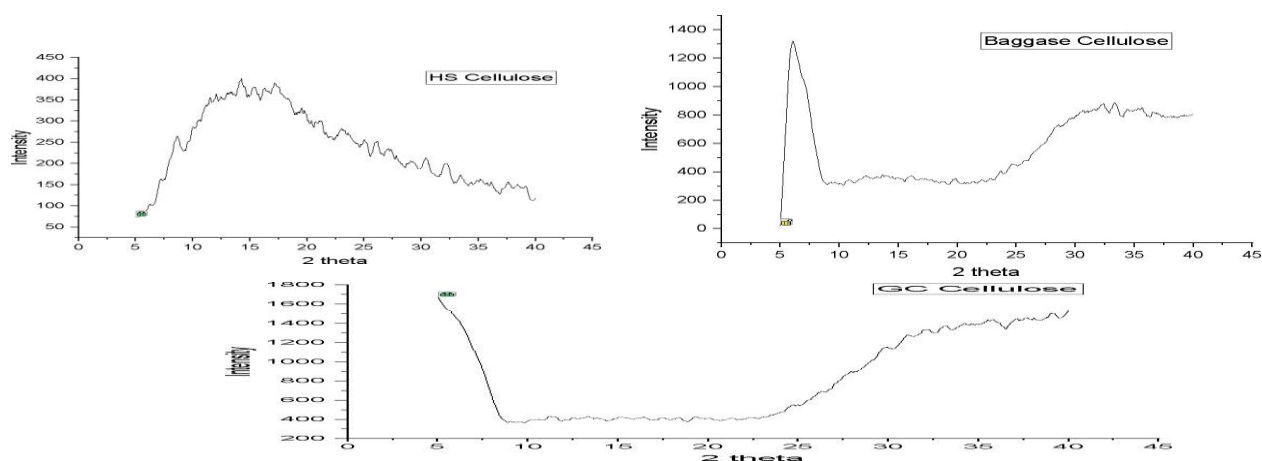


Figure 3.2: a) XRD graph of bacterial cellulose produced using HS media b) XRD graph of baggase cellulose c) XRD graph of glucose cellulose

Fourier Transform Infrared (FTIR) Spectroscopy

The spectra of the bacterial cellulose membranes were generated utilizing different carbon and nitrogen sources, and this data was compared with the standard HS media obtained bacterial cellulose as shown in Table 3.4.

Table 3.4: FTIR-ATR spectrum of Bacterial cellulose production through utilizing different culture mediums

Bond	Wavelength cm-1	Standard HS Media	Glucose and utilized tea	Bagasse and utilized tea
O-H bond stretch	3340	3343.22	3343.10	3343.90
C=O bond stretch	1630-1690	1637.38	1638.30	1635.54
C $\equiv$ C bond stretch	2100-2250	2161.70	2161.70	2162.42
C-N bond stretch	1316	-	1315.55	-
C-O-C bond stretch	1109	1109.78	1109.33	1107.64

Field Emission Scanning Electron Microscopy (FE-SEM)

Surface morphological characteristics of the sample sugarcane bagasse and utilized tea produced bacterial cellulose were performed using the variable pressure Field Emission Scanning Electron Microscope (FE-SEM) with an accelerating voltage at 5.00 KV. An image magnification of approximately 5000X, 8000X, 10,000X, 15,000X, 20,000X, 50,000X, and 100,000X were used. The micrograph of the bacterial cellulose sample was collected and recorded.

Sugarcane bagasse bacterial cellulose FESEM analysis at a magnification of 5000X and 8000X gave a diameter of 10 μ m, 4 μ m, fibrils size and densely packed, fibrous network of fibrils are present. The fibrils are irregular in shape and structure. The Figure (e-j) showed that with a Sugarcane bagasse bacterial cellulose at magnification of 10,000X, 20,000X, 50,000X, and 100,000X with a diameter ranging from 1 μ m, 4 μ m, and 5 μ m size fibrils. The fibrils were more fragile and fragmented structures containing the small pores that are connected with the fibrils with the neighboring cell walls in a packed form. Besides, this bagasse bacterial cellulose poses a smoother surface, strong fibrous network of nanofibers with different diameters, irregular in shape and arranged in a discontinuous manner. . The morphological characteristics and microstructure of BC were identified as they contain characteristics of nanostructure and microfibrillar arrangement of cellulose that is naturally present in plant-based cellulose. This suggests that sugarcane bagasse bacterial cellulose produced from inner pitch have nanofibers

and nanostructure that would be used in many future applications for the product formation from sugarcane bagasse bacterial cellulose.

CONCLUSION

In this study, the comparison of HS media, Glucose, and Sugarcane Bagasse medium was successfully done for bacterial cellulose production. The results concluded that sugarcane bagasse and utilized tea are cheaper alternative substrates for obtaining bacterial cellulose. This low-cost bacterial cellulose production has a characteristic feature of natural cellulose that can significantly contribute to the production of sustainable products such as edible films, facemasks, and cling sheets. Furthermore, this overall experimental research work highlights a new approach to provide an eco-friendly, low cost, biodegradable, higher cellulose production from food waste. Sugarcane bacterial cellulose is ideal for the sustainable production of products that will reduce food waste and align with the mission of SDG 12 “Ensure sustainable consumption and production patterns”. There is a need to perform further analysis for characterizing the bacterial cellulose and its production at a higher scale.

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