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# Designing with Bacterial Cellulose: A Pilot Study Using Localized Food Sources to Grow Innovative Materials in Vietnam

**Donna Cleveland** , **Rajkishore Nayak** and **Frances Joseph**

Dr. Donna Cleveland is an Associate Professor and the Interim Dean of the School of Communication and Design at RMIT Vietnam. Her research focuses on material innovation, circular design, and sustainability in fashion and textiles. She has led several international projects on biomaterials and community-driven sustainable design.  
[donna.cleveland@rmit.edu.vn](mailto:donna.cleveland@rmit.edu.vn)

Dr. Rajkishore Nayak is working as an Associate Professor with the School of Communication & Design (SCD) at RMIT University Vietnam. His research areas include circular fashion; waste management; corporate social responsibility; green supply chain, new and advanced materials. He is also involved in teaching bachelor of fashion

**ABSTRACT** The need for sustainable and environmentally friendly processes in material and textile manufacturing has heightened interest in utilizing renewable and non-damaging sources that can be either biodegradable or recyclable. One promising alternative is bacterial cellulose (BC), which can be created through the brewing process of kombucha. In addition, the BC can be grown from food byproducts or food waste using cost-effective methods, and offers a multitude of applications in the fashion, textile, and food packaging industries. This paper focuses on the BC candidate ingredients found in Vietnam, a developing nation that currently contributes to some of the highest volume of plastic waste in the world. The paper explores BC growing methods, factors that affect the aesthetic material outcomes, and highlights results from experiments

conducted at RMIT Vietnam. With locally available ingredients such as black tea, oolong tea, dragon fruit, mango and banana, a range of BC samples have been successfully grown to develop BC-based textiles. Through the study, it was observed that factors such as the concentration of growing mediums, pH levels, ambient conditions, and time influence the growth of BC. Additionally, through stakeholder feedback, the study examines the properties of these prototype textiles to identify potential applications. These newly developed materials could be utilized for clothing, accessories, and food packaging to address the harmful production and waste issues created by current textile technologies.

**KEYWORDS:** Bacterial Cellulose, Local Material Properties, Sustainable Textiles, Stakeholder Feedback, Experimental Practice

students and supervising PhD students in the areas of fashion sustainability.

Dr. Frances Joseph is a Professor of Material Futures at Huri te Ao, the School of Future Environments at Auckland University of Technology, New Zealand.

Her research explores materiality, making, and place through new materialist frameworks. She specializes in smart textiles, localized production, and bio-manufacturing, engaging in both theoretical and applied textile research.

## Introduction

In this article, the production of bacterial cellulose (BC) in Vietnam using local food sources and its potential applications in design are reported. The discussion includes the advantages of BC as a sustainable alternative to traditional materials and the challenges of designing with this innovative biomaterial. BC is positioned as a prime candidate for a broad range of applications, from biomedical engineering to sustainable fashion manufacturing (Gama et al., 2016; Klemm et al., 2005) due to its exceptional strength, high purity, non-toxicity, and biodegradability which often surpasses that of other natural materials, such as cotton or silk (Gama et al., 2016). Additionally, its absorbent nature allows it to retain up to 100 times its weight in water (Gorgieva & Trček, 2019). An outstanding feature of BC is its sustainability in using local resources and even waste. Unlike traditional materials like cotton or polyester, which require significant water and energy resources, BC can be grown using local food sources (Gama et al., 2016). This approach offers communities in developing nations like Vietnam the opportunity to cultivate their own materials, thereby reducing dependence on imports and promoting economic development (Cleveland et al., 2025).

Central to this exploration is kombucha, traditionally brewed from black tea through fermentation by a symbiotic culture of bacteria and yeast, known as SCOBY (Symbiotic culture of bacteria and yeast). Lee (2014) highlighted SCOBY's potential as a biomaterial, suggesting its use as an alternative to synthetic fabrics or leathers. This research extends previous studies by examining the impact of sugars and drying methods on the resulting biomaterials.

The microbial composition of a SCOBY is crucial in determining the physical characteristics of the produced BC. Its capacity for multiple brewing cycles underlines the adaptability of SCOBY, showcasing the possibility of continual growth and fermentation initiation

under suitable conditions (Gama et al., 2016). Designing with BC offers numerous possibilities; by adjusting fermentation conditions, attributes such as thickness and porosity of the material can be tailored to meet specific design requirements (Gama et al., 2016). Unlike plant-derived cellulose, bacterial cellulose from specific bacterial strains fermenting sugars, lead to a pure and consistent material adaptable to various configurations (Domskiene et al., 2019; Wood et al., 2023). The bacteria and yeast commonly found to make up SCOBY are robust sugar fermenters. These microbes rely on various sugar sources in the kombucha base to facilitate survival and proliferation.

The research emphasizes the significance of post-brewing modifications, particularly drying of the bacterial cellulose derivative, in creating tangible biomaterial for textile applications. The outcomes, displaying diverse sizes, textures, and colors, are indicative of the varied brewing techniques and ingredients used. The aim was to explore how modifications in the experimental design could influence the biomaterial's properties and its potential future applications, particularly within the communities sourcing the ingredients (Cleveland et al., 2025).

### **Bacterial Cellulose for Textile Applications**

The urgency for adopting sustainable and environmentally friendly materials in fashion and textile manufacturing has intensified in recent years (Niyazbekova et al., 2018). Traditional manufacturing practices, heavily reliant on non-renewable resources, contribute to substantial waste generation, exacerbating environmental degradation and accelerating climate change. In this regard, the problem of plastic pollution is the major concern as it has impacted millions of people's livelihoods, and social well-being. It has negatively impacted the planet by modifying habitats and natural processes in addition to reducing ecosystems' capacity to adapt to climate change. This scenario has sparked an increased interest in identifying and utilizing alternative materials that are renewable, biodegradable or recyclable, aiming to reduce the ecological footprint of these industries.

In this context, 'sustainability' refers to processes and materials that minimize environmental impact and promote resource efficiency. Sustainable materials are those that can be produced without harming the environment or impacting human health. Usually produced from recycled or renewable materials, they are designed to be durable and biodegradable. The manufacturing of these materials should not deplete resources or harm natural cycles, reflecting both environmental and social responsibility. BC, as explored in this study, embodies these principles through its production from renewable resources and its potential to replace synthetic materials.

In this study, the term 'textile' refers to materials derived from bacterial cellulose sheets that possess unique properties conducive to textile applications. While traditionally, textiles are understood to

include woven or knitted materials characterized by properties such as drape, breathability, and flexibility, bacteria cellulose-derived textiles differ significantly. BC textiles, as referenced in this research, are primarily non-woven sheets produced through microbial fermentation. These sheets exhibit high tensile strength and moldability, but do not inherently possess the drape and breathability typical of conventional fabrics like cotton or silk.

However, the manipulability of BC during its production process allows for modifications that can enhance these properties. For instance, the physical treatment of BC sheets, such as mechanical beating or incorporation of softening agents, can increase their flexibility and potentially their drape. Additionally, BC's porosity, which contributes to its breathability, can be adjusted through the control of fermentation conditions and post-fermentation treatments. Similarly, application of some colours or surface finishes can improve the aesthetics and surface texture of the BC samples.

This study explores the potential of BC not only as a sustainable alternative to synthetic textiles, which are often petroleum-based and contribute to microplastic pollution but also investigates the processing techniques that can render BC suitable for conventional textile applications. Furthermore, recent research by Wood et al. (2023) has demonstrated the effective application of BC in fashion apparel, assessing its performance properties and further confirming its viability as a sustainable textile material.

Amongst various alternatives, BC has been recognized for its considerable potential in sustainable applications (Gorgieva & Trček, 2019). BC, a naturally occurring polymer produced through the fermentation process by specific bacterial strains, exhibits remarkable properties such as high tensile strength, flexibility, transparency, and biocompatibility, rendering it suitable for a broad spectrum of applications (Nayak et al., 2025; Keshk, 2014). The practical applications and textile performance of BC have been substantiated in recent studies, which explored its use in creating sustainable fashion and textiles, highlighting its strength and flexibility as key factors for its adaptability in the textile industry (Wood et al., 2023).

The production process of BC, particularly through kombucha brewing, underscores its potential as a scalable and cost-effective method. Utilizing kombucha as a culture medium leverages the fermentation process of tea. The cultivation of BC from food byproducts or waste represents an innovative strategy that addresses waste management challenges, optimizes resource utilization, and offers sustainable alternatives to hydrocarbon-based materials, thus contributing to environmental conservation efforts.

In Vietnam, the management of plastic waste poses significant challenges, with the country contributing to one of the highest volumes of plastic waste worldwide, leading to severe environmental pollution (Nguyen & Tran, 2018). Vietnam is among the top ten countries in the global plastic pollution list with about 8,000 tons of plastic

garbage generated per day. The wide application of single-use plastic is the major problem that needs urgent solutions. The exploration of sustainable materials like BC is thus imperative for Vietnam's efforts to alleviate waste-related issues and foster more environmentally friendly practices.

Fruits are utilized in the BC production process primarily as carbon sources, providing the essential sugars needed for microbial growth. The sugars derived from fruits such as dragon fruit, mango, and banana not only serve as metabolic substrates but also impact the physical and chemical properties of the produced BC. The type and concentration of fruit sugars can influence the rate of microbial fermentation and the structural characteristics of the cellulose, such as thickness, strength, and flexibility. Utilizing fruits also aligns with the principles of sustainability by repurposing agricultural byproducts and reducing waste.

This research investigated the feasibility of cultivating BC using locally sourced ingredients in Vietnam, such as black tea, oolong tea, dragon fruit, mango, and banana. The objective was to assess the domestic production potential of BC and its applications in textiles, fashion, and food packaging, tapping into local resources to explore sustainable material solutions (Thakur & Thakur, 2014; Niyazbekova et al., 2018).

A critical aspect of the study involved identifying the variables that influence BC growth and its aesthetic properties. Stakeholder feedback on the developed BC textiles has illuminated potential applications and market viability. Analyzing growth medium concentration, pH levels, ambient conditions, and time, this research adds insights to the sustainable material design field, advocating for the adoption of BC as an alternative to traditional, fossil fuel-dependent textiles.

The implications of these initial findings suggest pathways for mitigating the adverse environmental impacts associated with current textile production technologies. By harnessing local resources, Vietnam could decrease its dependency on non-renewable materials, reduce plastic waste generation, and advance towards a more sustainable future in the fashion, textile, and food packaging sectors.

### ***Importance of Sustainable and Environmentally Friendly Materials***

The demand for sustainable and environmentally friendly materials in various industries has gained significant attention due to the urgent need to address environmental challenges. Traditional manufacturing methods in textiles and other sectors predominantly hinge on non-renewable resources, leading to extensive environmental repercussions (Niyazbekova et al., 2018). The extraction and processing of such resources contribute to greenhouse gas emissions, endanger natural habitats, and contaminate air, water, and soil (Costa et al., 2021).

The adoption of sustainable materials offers multifaceted advantages for the environment and society. Primarily, they present alternatives to exhaustible resources, leveraging renewable and biodegradable inputs

instead (Kamiński et al., 2020). This shift curtails dependency on non-renewable resources, thereby diminishing carbon emissions and mitigating the ecological footprint associated with traditional manufacturing (Costa et al., 2021).

Such transformation is crucial for mitigating climate change and the realization of global sustainability objectives. Additionally, the inherent biodegradability or recyclability of sustainable materials facilitates waste reduction and champions a circular economy (Niyazbekova et al., 2018).

Notably, the fashion industry's reliance on synthetic, petroleum-based textiles, which constituted 64% of the global fibers market in 2021 (Textile Exchange, 2021), exemplifies this challenge. Synthetic fibers, derived from non-renewable petroleum resources, not only deplete finite reserves but also contribute to pollution throughout their lifecycle. Concurrently, renewable fibers like cotton, while seemingly a more sustainable option, pose their own environmental challenges. Cotton's cultivation is notoriously water-intensive, consuming a significant portion of the world's freshwater resources, and its processing into textiles further exacerbates its ecological impact (Hossain & Khan, 2020). These factors underscore the complexity of achieving sustainability in textile manufacturing and the necessity of exploring innovative material solutions.

In contrast to synthetic materials, which can linger in ecosystems for centuries, sustainable alternatives degrade over time, minimizing persistent environmental harm (Gorgieva & Trček, 2019). This is especially pertinent considering industries like fashion, textiles, and food packaging, notorious for their prodigious waste generation (Niyazbekova et al., 2018).

Beyond the ecological impact, the adoption of sustainable and environmentally friendly materials is aligned with evolving consumer trends and societal norms. Modern consumers are increasingly conscious of the environmental impact of their purchasing decisions, and they show a growing demand for products that are ethically and sustainably produced (Deloitte, 2023). By integrating sustainable materials into their products, companies can enhance their brand reputation, attract environmentally conscious consumers, and contribute to a more responsible and sustainable economy.

### ***Introduction to Bacterial Cellulose (BC) and Its Potential Applications***

BC stands out as a naturally occurring polymer, characterized by a unique structure and remarkable properties that make it a prime candidate for various applications. It originates from specific bacterial strains that, during fermentation, produce cellulose nanofibers, resulting in a dense network (Gorgieva & Trček, 2019). Unlike plant-based cellulose, BC boasts enhanced mechanical strength, high purity, and biocompatibility, factors that position it as an ideal candidate for multiple applications (Kamiński et al., 2020).

One of the key advantages of BC is its alignment with sustainable production methodologies. Renewable resources, spanning agricultural waste, food byproducts, and even the kombucha brewing process, can foster BC cultivation (Keshk, 2014; Costa et al., 2021). This approach offers a viable, environmentally friendly, and cost-efficient alternative to synthetic materials that rely on non-renewable resources. Moreover, BC production is inherently low waste, with byproducts frequently repurposed as recyclables or nutrients sources (Gorgieva & Trček, 2019).

In the area of textiles and fashion, BC's unique properties pave the way for its transformation into fibers and fabrics endowed with desirable characteristics, such as high tensile strength, flexibility, and breathability (Domskiene et al., 2019; Wood et al., 2023). Such BC-based textiles emerge as sustainable contenders against fossil fuel-based textiles, which are often non-biodegradable and contribute to pollution and waste issues (Lee, 2014; Gorgieva & Trček, 2019).

Extending beyond the textiles industry, BC has shown promise in areas including biomedical materials, wound dressings, tissue engineering scaffolds, and drug delivery systems (Gorgieva & Trček, 2019). Given its biocompatibility and moisture retention capabilities, BC is suitable for medical and healthcare applications (Domskiene et al., 2019; Wood et al., 2023). In the food packaging sector, BC materials showcase benefits like high water-holding capacity, barrier properties, and biodegradability, thereby outperforming conventional plastic packaging (Keshk, 2014).

The versatility of BC, coupled with its expansive application potential, makes it a valuable area of research and development. As researchers and industries explore the unique properties of BC, they unlock potential avenues for creating sustainable, biodegradable, and innovative materials that respond to urgent environmental and societal challenges.

### ***Biochemistry of Kombucha***

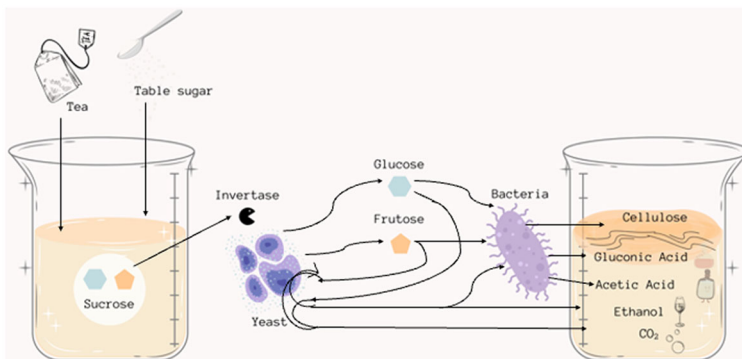
Kombucha brewing involves a sequence of biochemical reactions, arising from the fermentation process carried out by a symbiotic community of bacteria and yeast (SCOBY). This community consists of specific bacterial and yeast species that contribute to the microbial profile of kombucha (Villarreal-Soto et al., 2018). During the fermentation phase, the SCOBY utilizes the sugars present in the sweet tea mixture for energy production. This metabolic process, termed microbial fermentation, allows bacteria, yeast, and fungi to convert carbohydrates into energy. The yeast and bacteria within the SCOBY work synergistically through specific enzymatic pathways to biochemically process the sugar sources (Villarreal-Soto et al., 2018).

Sucrose, a common sugar naturally found in plants and fruits, serves as the primary sugar source in traditional kombucha brewing. Structurally, sucrose is a disaccharide consisting of two monosaccharides - fructose and glucose, covalently bonded together. Yeast

cells within the SCOBY facilitate the breakdown of sucrose into these simple sugars, a reaction catalyzed by the enzyme invertase (May et al., 2019), subsequently utilized by the bacteria for energy production (Figure 1).

Predominantly, the bacterial species present in the SCOBY for kombucha brewing are those producing acetic acid and lactic acid, both of which play crucial roles in the fermentation process. Acetic acid, a relatively mild acid, gives kombucha its distinctive tang reminiscent of vinegar. Several bacteria strains commonly found in kombucha produce acetic acid as a by-product of glucose consumption in oxygen-rich conditions, while fructose consumption gives rise to lactic acid (Antolak et al., 2021; Villarreal-Soto et al., 2018). During this process, gluconic acid is also produced as another metabolic byproduct, contributing to the biochemical complexity of the resulting kombucha (Amr & Ibrahim, 2022).

To ensure maximal energy yield and a harmonious symbiotic environment, it is imperative to maintain a balance of both bacterial types. The progression of fermentation culminates in the emergence of a biodegradable BC layer atop the brewing medium. This stratified structure owes its formation to aerobic, gram-negative bacteria active during sugar fermentation in the presence of oxygen (Amr & Ibrahim, 2022). While the sugar source might vary, the consistency in the BC layer's formation is retained. It is important to note that the BC layer produced during fermentation is not solely composed of cellulose. The layer also includes a variety of microbial species integral to the fermentation process, such as bacteria and yeast from the SCOBY. These microorganisms contribute to the formation of the cellulose matrix but must be removed to achieve the pure cellulose needed for practical applications. The purification of BC involves several steps to remove these microbial species, ensuring that the resulting material is free of biological contaminants. This process is critical for



**Figure 1**

Biochemical breakdown of sucrose in Kombucha brewing: Illustrating the conversion of sucrose into fructose and glucose by yeast cells within the SCOBY and their subsequent utilization by bacteria for energy production, including the production of byproducts such as gluconic acid and acetic acid. Created with canva.

applications where the purity of cellulose is essential, such as in biomedical applications or in the production of high-quality textile fibers. Grasping the biochemical intricacies of kombucha fermentation equips researchers and practitioners with the knowledge to leverage the microbial dynamics at play, thus facilitating a sustainable and renewable BC source tailored for diverse applications.

### ***What is Cellulose?***

Cellulose is an organic compound, a polysaccharide consisting of a linear chain of several hundred to many thousands of linked D-glucose units. It is the primary structural component found in plant cell walls and represents the most abundant organic polymer on Earth (Klemm et al., 2005). Cellulose provides plants with rigidity and resistance against external environmental pressures.

The molecular arrangement of cellulose fibers gives them high tensile strength, making them essential for maintaining the structural integrity of plants. The fibers are held together by hydrogen bonds, forming a crystalline structure that is insoluble in water and resistant to many chemical treatments.

In the context of kombucha brewing, the SCOBY, while fermenting the sugars, produces a layer of BC. BC, while chemically identical to plant cellulose, has a unique nano-fibrillar structure. It is this structure that grants BC its distinctive mechanical and physical properties, making it a material of interest in diverse applications, from textiles to biomedicine (Gama et al., 2016).

Thus, while cellulose is traditionally associated with plants, certain bacterial communities, like those present in a SCOBY, can produce this versatile biopolymer. When referring to the product of kombucha fermentation, the term "bacterial cellulose" (BC) is used to distinguish it from its plant-derived counterpart.

### ***Fruits as a Source of Sugar***

Fruits, in their natural state, are abundant reservoirs of sugars, primarily in the form of fructose, glucose, and sucrose (Amr & Ibrahim, 2022). Beyond their nutritional value, these sugars are pivotal in fermentation processes, acting as primary substrates for various microorganisms to produce energy and secondary metabolites (Soto et al., 2020). In the context of kombucha brewing and BC production, sugars function as an indispensable resource. While traditional kombucha recipes often involve refined sugars, there is an increasing inclination towards seeking natural alternatives. Here, fruits, laden with their inherent sugar content, emerge as promising candidates.

Fruits as a sugar source provides many advantages. Firstly, sourcing fruits locally or repurposing waste fruits can significantly diminish the carbon footprint traditionally associated with the transportation and refinement of sugar, resonating with the broader theme of sustainable and environmentally friendly practices. Secondly, the diverse

sugar profile of different fruits can potentially lead to unique kombucha flavors and more importantly in this research to distinctive BC properties (Villarreal-Soto et al., 2018). Beyond just sugars, fruits are also carriers of a plethora of vitamins, minerals, and organic compounds that might influence the fermentation process and the resultant quality of BC. Additionally, the utilization of waste fruits or by-products from the food industry serves a dual purpose – it offers a method to mitigate waste while simultaneously providing a valuable resource for kombucha brewing and BC production.

Especially in the context of Vietnam, with its rich and diverse fruits like dragon fruit, mango, and banana, these not only symbolize cultural staples but also represent potential sugar reservoirs for sustainable BC production. By harnessing the sugars present in these fruits, this research explores a novel avenue for BC production, one that underscores local resources, sustainability, and innovation (Cleveland et al., 2025).

### ***The Problem of Plastic Waste in Vietnam***

Vietnam faces a significant challenge in managing plastic waste, which has reached alarming levels in recent years. Plastic production relies heavily on fossil fuels, contributing to greenhouse gas emissions and exacerbating climate change (Trinh et al., 2021).

The textile industry's reliance on synthetic, petroleum-based textiles like polyester and nylon further exacerbates environmental issues. These materials, like plastic, are derived from fossil fuels and are a major source of microplastic pollution. Polyester and nylon, constituting a significant portion of the global fiber market, persist in the environment, breaking down into microplastics that pollute waterways and oceans (Vassilenko et al., 2021). In addition to plastic waste, Vietnam grapples with managing fabric waste. The "Industrial Fabric Waste Flow" report reveals a complex journey of fabric waste from production to disposal, with a substantial amount ending up in informal waste streams or landfills, highlighting a critical gap in recycling and treatment processes (Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2021).

The scale of the plastic and fabric waste problem in Vietnam demands urgent action and exploration of sustainable alternatives. Finding innovative solutions to reduce waste generation, promote recycling, and develop eco-friendly materials is crucial for mitigating the environmental impact and building a more sustainable future. The utilization of BC as an alternative to fossil fuel-based plastics and textiles holds immense potential for addressing the waste problem in Vietnam. BC offers biodegradability, and recyclability, and can be produced from local resources such as food byproducts or agricultural waste (Costa et al., 2021). By leveraging the brewing process of kombucha and the biochemistry of BC production, Vietnam could transform some current waste streams into valuable and sustainable materials.

Integrating BC-based materials into various industries, including fashion, textiles, and food packaging, could significantly reduce the dependence on single-use plastics and synthetic fibers, contributing to a circular economy (Costa et al., 2021). For example, BC-based textiles can provide a biodegradable and environmentally friendly alternative to traditional synthetic fibers, which are non-biodegradable and contribute to microplastic pollution (Gorgieva & Trček, 2019). Addressing the plastic and fabric waste problem in Vietnam requires a multi-faceted approach, involving policy interventions, infrastructure development, and the promotion of sustainable material alternatives. By embracing the potential of BC and other eco-friendly materials, Vietnam can make significant strides toward mitigating waste, reducing environmental pollution, and fostering a more sustainable society.

### **Materials and Methods**

In the pursuit of understanding the potential of BC when cultivated with various Vietnamese food sources, the study navigated the complexities of an integrated methodological approach. This study adopted a 'Hybrid Research Design' that merges both experimental and evaluative paradigms (Creswell et al., 2011; Johnson & Onwuegbuzie, 2004). This design not only ensured a rigorous exploration of BC cultivation and its potential applications but also contextualized its importance through stakeholder feedback. The experimental research design focused on systematic cultivation of BC using an array of local food sources. The preliminary phase determined optimal conditions for BC cultivation, including parameters like pH, temperature, and nutrient content. Following this, we tested a variety of food sources, including different teas and fruits, aiming to discern their impact on BC growth and attributes. Data collection was conducted at regular intervals, specifically targeting factors that directly influenced the appearance of BC. This included monitoring the types of ingredients used, pH levels, days of growth, ambient temperature, and the thickness of the BC, as these elements were critical to determine the final visual and tactile qualities of the material.

The maturity thickness of 0.6 cm for harvesting BC was selected based on previous empirical findings. This specific thickness was determined to optimize the mechanical properties essential for further processing and application in textile production. At 0.6 cm, the BC layers provide sufficient structural integrity and flexibility required for subsequent mechanical testing and textile manufacturing processes. Thinner layers, while easier to handle and possess better drape, tend to be less durable and more prone to tearing during processing, whereas thicker layers may restrict the desired textile-like drape and flexibility.

The harvested bacterial cellulose was carefully separated from the vessel and rinsed under cold water to remove surface residues. To ensure thorough purification, the material was soaked in fresh water

for 1 to 3 days with daily water changes, allowing for the diffusion of any remaining microbes and byproducts, thereby enhancing its purity and mechanical properties.

The harvested bacterial cellulose material underwent a series of drying and coating procedures designed to optimize its physical properties for potential textile applications. The fabric was laid flat on a clean, dry, and debris-free wooden surface or patterned drying mat. For outdoor drying, it was positioned in an area with indirect sunlight and regularly checked to ensure even drying. Indoor drying was carried out with fans in a well-ventilated area, which allowed for controlled environmental conditions, reducing contamination risks and achieving desired flexibility. The weighted drying method involved sandwiching the fabric between two wooden panels with a brick or weight on top to remove excess moisture and ensure uniform thickness, crucial for maintaining dimensional stability. Patterned drying using bamboo or coconut/palm leaf mats introduced unique textures and patterns, enhancing the aesthetic appeal of the material.

Coating methods, including beeswax and coconut oil applications, were selected to increase the durability, water resistance, and tactile quality of the BC sheets, aligning them closer to traditional textile functionalities. Subsequent statistical analysis of this data aided the identification of patterns and deduction of conclusions about the most efficient food sources for BC cultivation.

Parallel to the experimental framework we included an evaluative research design, which assessed the real-world value and potential applications of the cultivated BC products. We engaged a diverse group of 9 stakeholders relevant to the study, including experts in textiles, design, environmental science, and business. Their qualitative feedback was instrumental in understanding the perceived strengths, potential applications, and areas of improvement for the BC materials. This feedback then shaped recommendations to refine the BC cultivation process and open avenues for further exploration (Creswell et al., 2011). Furthermore, an essential dimension of this methodology was the incorporation of traditional knowledge. Recognizing the richness of local approaches, we undertook field trips to local artisans, aiming to discover traditional methods that might enrich BC cultivation or processing. These methods were then experimented with, and their efficacy evaluated in the context of BC properties and alignment with local values.

## **Protocol**

### *Bacterial Cellulose Cultivation*

To initiate the BC cultivation process, a kombucha tea starter culture was prepared. This involved the preparation of a nutrient-rich tea solution, which serves as the growth medium. Specifically, 500 mL of water was boiled to which 300 g of sugar and 30 g of black or green tea were added and set aside to steep for 15 min. After cooling to

room temperature, this tea solution was mixed with 2.5 L of filtered water, and 300 mL of the starter culture was added. The mixture was then placed in a 20 L fermentation tank and allowed to incubate at room temperature for approximately 15 days. During this period, the pH of the medium was monitored, typically ranging between 2.7 and 2.94, with black tea solutions showing the lowest pH values.

The pH of the culture medium was monitored and adjusted to maintain a range between 4.0 and 5.0. This pH range is crucial as it optimizes the microbial activity, enhancing the fermentation process and ensuring the maximal yield of high-quality BC. Fluctuations outside this range can inhibit microbial activity or promote unwanted bacterial growth, compromising the integrity of the BC produced. Similarly, temperature control is vital, with the fermentation process conducted at a consistent temperature between 24 °C to 30 °C. This temperature range is optimal for the activity of the kombucha culture, promoting rapid microbial growth and efficient synthesis of BC. Deviations from this temperature range can lead to reduced fermentation efficiency or may alter the physical properties of the produced BC.

### *Growing Process*

The growth phase of bacterial cellulose involved a carefully controlled environment:

- The growing tank was thoroughly cleaned with white vinegar to eliminate unwanted bacteria and contaminants that might interfere with the SCOBY. This step ensures a sterile environment at the start of the fermentation process. Vinegar, being a natural disinfectant, effectively removes potential pathogens without leaving harmful residues, making it safe for subsequent cultivation steps.
- The freshly prepared sweet tea and starter culture mixture was introduced into the clean growing tank.
- The culture was allowed to ferment for 5–21 days at room temperature, away from direct sunlight. Maintaining a stable temperature between 28 and 32 °C was crucial.
- The growing tank was covered with a cotton muslin cover to provide adequate ventilation.

### *Harvesting*

Harvesting bacterial cellulose required specific criteria:

- Maturity was assessed by examining the thickness of the bacterial cellulose layer, which should be at least 0.6 cm thick.

- The harvested bacterial cellulose material was gently detached from the sides of the vessel and peeled away from the liquid's surface, moving towards the centre to prevent tearing.
- The fabric was rinsed under cold water to remove any tea residue or remnants of the culture.
- The fabric was placed in fresh water for an extended soak of 1 to 3 days, with daily water changes.

### *Drying*

Drying the bacterial cellulose fabric involved several steps:

- The fabric was laid flat on a clean, dry, and debris-free wooden surface or patterned drying mat.
- For outdoor drying, it was positioned in an area with direct sunlight and regularly checked to ensure even drying.
- Indoor drying required a well-ventilated area with fans to facilitate the process. The fabric was periodically rotated for uniform drying.
- A weighted drying method involved sandwiching the fabric between two wooden panels with a brick or weight on top to remove excess moisture.
- Patterned drying was achieved by using bamboo or coconut/palm leaf mats.
- The fabric was considered fully dried when it achieved a leathery texture and was no longer sticky.

### *Coating and Finishing*

Coating and finishing the dried BC fabric enhanced its durability and water resistance. The following steps were involved:

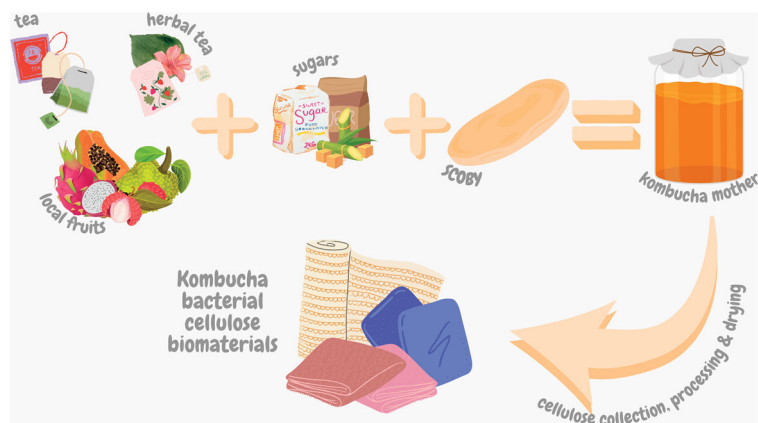
- Beeswax in either sheet form or pellets was applied by placing the fabric between two pieces of non-stick baking paper on a wooden board.
- The fabric was gently ironed to melt and distribute the beeswax evenly. A roller or tube was used to press the wax into the fabric.
- After cooling, the non-stick papers were peeled away, revealing the waxed fabric.
- A thin layer of coconut oil could be applied for a glossy finish, and the fabric was left to absorb the oil completely.
- Aftercare instructions included storing the coated fabric in a cool, dry place away from direct sunlight and reapplying beeswax and coconut oil if needed. These processes were adaptable based on the desired flexibility and finish for various applications, with thorough testing recommended for project-specific requirements.

- This comprehensive protocol ensured a systematic approach to BC cultivation and processing, which formed the basis for the research exploration. [Figure 2](#) shows a stylised diagram of the process.

### *Materials Library*

The experimental approach was structured around the development of a comprehensive materials library. This library served as a repository of BC samples cultivated under a diverse range of conditions, allowing for the exploration of the adaptability of BC when grown from various Vietnamese food sources. The library comprised over 150 samples, offering an extensive view of BC's versatility and its potential applications. Detailed documentation of each sample, focused on attributes such as texture, strength, flexibility, and aesthetic qualities, ensured a systematic assessment of BC's capabilities.

The systematic manipulation of growing parameters, including sugar sources, tea types, and fermentation durations, formed the foundation of the materials library. This deliberate alteration of conditions aimed to create an extensive array of BC samples, enabling us to explore the full spectrum of BC's possibilities. To effectively present this dataset to stakeholders, a structured approach was employed. Samples were organized into distinct sample boxes, each showcasing the outcomes of variations in specific growing conditions, such as type of tea feeders and sugar sources. These sample boxes simplified the presentation of complex data while also serving as tangible representations of the experimental results. Refer to [Figure 3](#) for examples of the sample boxes and labelling of the samples.



**Figure 2**

Stylised flow diagram of the methods to produce the bacterial cellulose biomaterials. Created with canva.

Similar systematic documentation and comparison of material properties to identify optimal materials for various applications are reflected in other research within the sustainable materials field. For example, Dumitrescu et al. (2022) explored the potential of orange waste films as bio-based textiles, utilizing a hybrid research method that emphasized the importance of systematically documenting the properties of these materials to contribute to textile sustainability. Their study underscores the value of a materials library in facilitating innovative textile production practices that contrast with traditional methods often reliant on petroleum-based materials.

The initial sample boxes, labelled as Box 1 and Box 2, featured samples cultivated with ‘standard kombucha teas’ including black, green, and oolong teas. These boxes also included samples grown with both white and brown refined sugars, providing initial insights into the influence of sugar type on BC characteristics. Subsequently, Box 3 introduced a unique dimension by incorporating samples grown without any additional sugar. This departure from the traditional sugar-aided fermentation process offered insights into BC’s inherent qualities when exposed to minimalistic growth conditions. The term ‘minimalistic growth conditions’ refers to the simplified and resource-efficient environment maintained during the cultivation of BC, where minimal nutrients and care are required to achieve effective growth.

Box 4 presented an exploration of BC’s interaction with indigenous Vietnamese ingredients. Here, fruits from local and widely available Vietnamese sources such as dragon fruit and mango were used exclusively. This approach aimed to highlight BC’s transformative potential when paired with locally available resources. Box 5 presented an innovative facet of the research, featuring BC samples subjected to colour-dyeing techniques during and after the growing and drying process (i.e. both in-situ and ex-situ). This not only



**Figure 3**

Samples boxes with bacteria cellulose samples. This shows the box design and the labelling on each sample. Each sample hung on a header card, detailing the specific details of the sample (Source: Authors’ own images).

introduced an aesthetic dimension but also showcased BC's adaptability to various post-production treatments.

Crucially, categorization into Box 1 and Box 2 was based on the source of sugar, distinguishing between refined and natural sugar types. This differentiation enabled us to examine how the sugar source influenced BC growth and properties, a pivotal aspect of the investigation.

In summary, the materials library is a comprehensive record of the depth and breadth of the research. It houses a diverse collection of BC samples, each representing a unique set of growth conditions, and was a valuable resource for stakeholders to evaluate the potential applications of the material.

### ***Integration of Traditional Drying Solutions and Field Research***

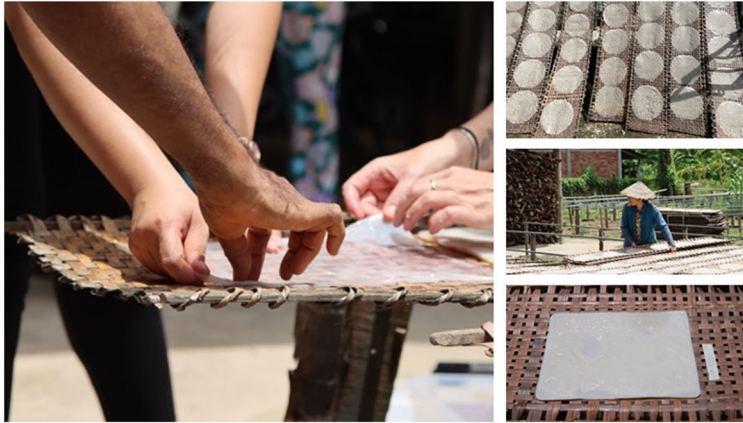
In an innovative approach to BC production, the methodology not only considered the scientific cultivation of BC but also explored traditional Vietnamese drying practices. This approach recognized the rich heritage of Vietnamese artisanal techniques, particularly in food preservation such as rice wraps, through the process of field research. We investigated and adapted these traditional methods for the BC drying process, offering an opportunity to blend scientific innovation with local wisdom. The traditional drying process for rice paper involved drying on a patterned surface (e.g. coconut mat) under direct sunlight facilitated by wind.

#### ***Field Research***

Field trips to Ben Tre and Tay Ninh provinces of Vietnam were driven by the objectives of observing and understanding the traditional rice paper drying processes. During visits to the rice paper factories, we documented the drying process and sought knowledge from local experts. Refer to [Figure 4](#) for images of the rice wraps and the bacteria cellulose sheets on the drying racks. These interactions provided insights into the sustainable use of natural elements such as sun and wind in drying, which are integral to traditional Vietnamese practices.

The generosity of the local artisans in sharing their drying racks allowed us to experiment with drying the BC samples in authentic conditions. This collaborative effort not only facilitated a practical application of traditional methods but also enhanced our understanding of their potential impact on the properties of BC. The racks provided by the factory owners were also brought back to the university for controlled experimental drying, further integrating traditional techniques into the research.

The visit to a local herbal garden in Tay Ninh expanded the exploration beyond drying techniques. Interaction with a traditional medicine doctor opened avenues for integrating natural dyes into BC production. The acquisition and subsequent use of butterfly pea tea



**Figure 4**

Visiting Bến Tre rice manufacturing facilities: Using their food drying racks to test drying bacteria cellulose materials. (Source: Authors' own images).

from their garden illustrated the potential of combining traditional plant-based dyes with BC cultivation, enriching the color and aesthetic appeal of the final product. Refer to [Figure 5](#) for images of the dyed cellulose sheets.

These field trips were instrumental in enriching the research methodology. By closely observing and engaging with traditional practices, the team adapted these sustainable methods to current BC production. This integration of field research with laboratory experimentation underscores a commitment to developing environmentally friendly and culturally resonant materials. The knowledge gained from these trips informed the drying processes and inspired innovative approaches to material development, ensuring the research was both scientifically rigorous and culturally relevant.

### **Stakeholder Evaluation**

The evaluative dimension of the research also involved feedback from nine interdisciplinary stakeholders. These stakeholders were presented with the materials library and asked to provide qualitative feedback. The sample boxes, showcasing the diverse range of BC samples, embodied the experimental practice. Stakeholders were encouraged to explore these samples, contrasting the outcomes of different cultivation conditions. Their insights, ranging from aesthetic evaluations to potential applications, were instrumental in gauging the appeal and possibilities for BC product development. By juxtaposing their feedback with the experimental data, holistic conclusions were drawn, and future trajectories were charted.

The stakeholder evaluation process was designed to engage experts from diverse fields, ensuring a comprehensive understanding of BC's potential. Recruitment was carried out through professional



**Figure 5**

Experimental dyeing techniques: Using butterfly pea tea and turmeric to grow and dye the bacteria cellulose materials (Source: Authors' own images).

networks and academic contacts, prioritizing individuals with expertise in materials science, sustainable design, and biotechnology. The evaluation sessions were held at our research facility in Ho Chi Minh City, providing a controlled environment that facilitated an in-depth exploration of the material samples. This setting also allowed for immediate discussion and interaction, which were crucial for gathering detailed feedback. The evaluation was led by the principal researcher, who introduced the session with a presentation on the objectives of the research, the properties of BC, and the context of its development. The researcher guided the stakeholders through the session, providing information about each sample and answering any questions that arose.

### ***Stakeholder Selection and Feedback***

An interdisciplinary panel of nine stakeholders was invited to review various biomaterial samples from the project. Stakeholders, selected for their diverse fields of research, provided comprehensive feedback. They physically evaluated the bacterial cellulose textile samples, representing different experimental biomaterials developed during the study. On the day all stakeholders were invited to one session where the research project was presented to them, including what biomaterials are and how they were derived from BC. In total five sample boxes were presented to the group. Each sample box was set up as a station around the room. The group were all given printed questionnaires and a pen. The aim was to collect the data and to stimulate discussions about potential applications, gathering comments on various characteristics. Stakeholders assessed twelve parameters using a Likert scale ranging from one to five, with five indicating the highest or best rating. The twelve parameters included smoothness,

softness, roughness, resiliency, compressibility, flexibility, foldability, aesthetic, color, thickness, smell, and transparency. Participants were asked to physically examine the textiles, assessing them against the criteria outlined. The session was interactive, with stakeholders encouraged to discuss their observations openly.

They also responded to questions concerning potential applications and purposes for the BC biomaterial (refer to [Table 1](#)).

After examining and ranking all sample boxes, stakeholders completed their questionnaires, which were then collected and analyzed by the research team. The results were used to identify patterns in stakeholder preferences and perceptions, which were critical for refining BC textile development.

This study was conducted under the project titled 'Material Futures: Experimental Fabrication of Bacterial Cellulose as a Potential Biomaterial', with ethical approval granted by the Ethics Committee of RMIT University (project ID: 25441). All procedures involving human participants were in accordance with the ethical standards of the institutional research committee and ethical standards. Prior to participation, all participants were fully informed about the study's

**Table 1** Questionnaire from the stakeholder feedback panel (Source: Authors' own)

Survey categories		
<b>Design outcomes</b>	1. What are the potential design outcomes of growing, harvesting and drying Kombucha biomaterials in Vietnam?	3. From your disciplinary perspective what areas for future research would you recommend for growing Kombucha as an alternative material?
<b>Biomaterials as an alternative option</b>	2. Do you think Kombucha leather has a potential to replace traditional leather?	5. What are some of the benefits and limitations of the different samples?
<b>Growth conditions to manipulate the physical outcome</b>	4. How do the different ingredients such as teas and sugars used to grow the Kombucha alter the tactility and other properties of the new biomaterials?	6. What is the potential of replacing the existing raw materials with the new biobased materials derived from Kombucha for different applications?
<b>Consumer applications</b>	7. What applications do you think this material might be useful in?	8. What end uses would you suggest?

purpose and the use of their data in research outputs. Written consent was obtained from each participant, confirming their understanding that their involvement was voluntary and that they could withdraw from the study at any time.

## **Results**

### ***Visual Evaluation by Stakeholders***

The visual appeal of biomaterials plays a crucial role in determining their potential applications. Stakeholders in the study provided valuable insights into the visual properties of the BC-based textiles. These properties encompassed aspects such as luster color, surface texture, and overall appearance.

### ***Color***

Stakeholders assessed the color of the BC-based textiles, offering valuable feedback on their visual appeal. Notably, we observed variations in color perceptions across different sample types, reflecting the diversity of the materials library.

The Samples from boxes 3 and 4 garnered the highest ratings for visual appeal. Stakeholders consistently rated these samples above 80% in the respective color categories. The average ratings for these categories were 3.7 and 3.8, respectively for box 3 and box 4, indicating a strong preference for the colors achieved through specific cultivation conditions.

The samples in box 5 scored the next highest rating in visual appeal, albeit below the overall average. While not reaching the same levels as the types from sample boxes 3 and 4, these samples still demonstrated strong visual qualities in color and texture.

### ***Standard Kombucha Protocols***

In contrast, the samples grown under standard kombucha protocols received lower ratings in the visual aspect of the biomaterial properties, suggesting that standard cultivation conditions yielded less visually appealing results.

Additionally, stakeholders provided valuable insights regarding color preferences and potential applications for BC-based textiles. Stakeholder 1 emphasized the importance of color in crafting prototypes for disposable products and decorative items. Stakeholder 3 highlighted the aesthetic appeal of these materials, suggesting potential applications in belts and shoe components, which aligns with their positive ratings for visual appeal. Stakeholder 7 noted the significance of color in fashion accessories and interiors. These findings underscore the crucial role of color in the acceptance and potential use of BC-based textiles, especially in design and fashion-related applications, as highlighted by stakeholders' feedback.

## **Texture**

Texture is another crucial aspect of bio-based materials that significantly impacts their usability and appeal. Stakeholders' evaluations of texture properties offered valuable insights into the tactile qualities of BC-based textiles.

## **Smoothness and Softness**

The BC samples from box 3 exceeded other samples in the areas of smoothness and softness, with average scores of 4.14 and 4.28, respectively. These findings suggest that specific cultivation conditions can yield BC-based textiles with exceptionally smooth and soft textures, which could be advantageous in various applications.

## **Roughness**

The BC samples in box 5 scored the highest for roughness, indicating a different textural quality. This suggests that alternative cultivation methods may result in BC-based textiles with unique tactile characteristics of roughness. The rough textured textiles have special demand for applications such as upholstery, home-furnishing, and rustic-themed interior design.

## **Resilience, Compressibility, and Flexibility**

BC sample from box 2 were the most resilient and flexible, scoring the highest in these categories. These attributes are essential for determining the durability, performance, and usability of BC-based materials.

## **Foldability**

Foldability is an essential property of textiles while they are stored in folded condition. The textile material should retain its shape, properties, and appearance after it is unfolded. Surprisingly, sample box 3 scored highest in the foldability scale. These results suggest that stakeholders agree on which BC-based textiles exhibit greater foldability, which is a key factor in applications like packaging and fashion. Moreover, stakeholders' feedback provided additional context regarding the tactile properties of BC-based textiles. Stakeholder 1 emphasized the importance of texture in prototyping and experimentation across various product types and material uses. Stakeholder 8 suggested that BC-based materials could act as a substitute for leather in clothing and furniture industries, emphasizing the relevance of texture in these applications. Stakeholder 6 acknowledged the wide-ranging potential applications of BC-based materials, including apparel and decor, further underlining the significance of texture in determining usability and appeal. These insights highlight the

multifaceted influence of texture on the suitability of BC-based textiles for diverse applications, as perceived by the stakeholders.

### **Olfactory Evaluation by Stakeholders**

The smell or olfactory properties of bio-based materials can influence their acceptability and potential applications. In this section, we explore the olfactory evaluations provided by stakeholders.

#### **Smell**

Stakeholders' feedback on the quality of the cellulose products' smell revealed intriguing insights. The samples in box 5 received the highest average scores, approximately 73%, regarding the quality of the cellulose product's smell. Stakeholders found these samples to have particularly pleasant or distinctive odors. Samples from box 3 also scored well in terms of smell quality, with many respondents providing "good" and "great" responses.

#### **Other Types**

While some other samples presented similar responses across the surveyed feedback, some samples from the other boxes received mixed feedback, suggesting that the smell quality appeared as a weakness for some of the samples. Incorporating insights from the stakeholders' feedback on smell, specific cultivation conditions play a significant role in shaping the olfactory properties of BC-based textiles. Stakeholder 6's observation about the "sweet smell" being both a benefit and limitation aligns with the feedback provided about sample box 5, highlighting the positive reception of pleasant odors. This feedback provides valuable guidance for potential applications where the olfactory aspect is a critical consideration. Stakeholder 8's comments regarding the smell quality of different sources further underscore the importance of cultivation conditions in influencing the olfactory properties of BC-based textiles. They made a comment about the samples grown from fruit and juice, being "more aesthetically pleasing, a nicer texture, handle and color and they smell good". These insights contributed to our understanding of how smell can impact the acceptability and desirability of BC-based materials in various contexts.

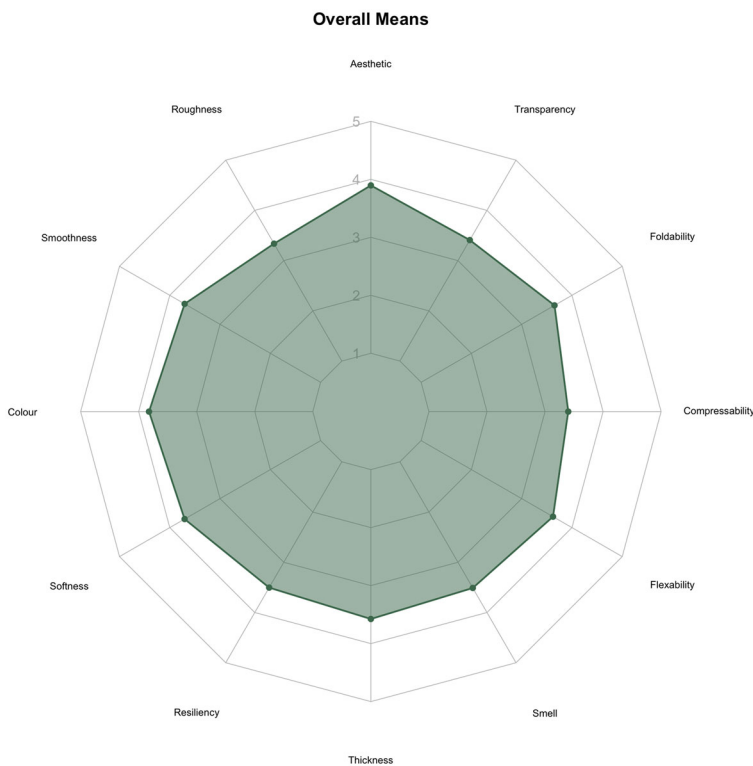
The feedback provided by stakeholders regarding color, texture, and smell contributed valuable insights about the visual and tactile qualities of BC-based textiles, providing guidance for their potential applications and usability.

### **Stakeholder Feedback Analysis**

In this section, the results of the stakeholder feedback analysis, focusing on material quality evaluations, are presented. Stakeholders

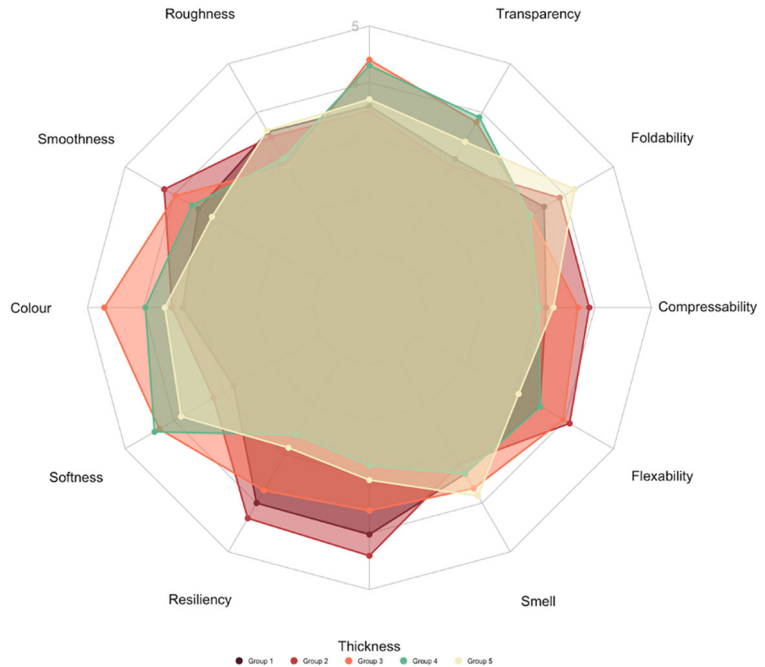
rated twelve parameters from one through five and answered questions related to potential applications and purposes for the BC biomaterial. Figure 6 provides an overview of the overall average ratings for the material quality of each sample box, based on the evaluations of eight participants. Notably, the feedback indicated that the quality of the biomaterial properties was consistently uniform across the assorted samples, with no single property emerging as an exclusive strength.

One stakeholder's score was excluded from the data analysis as it was filled in incorrectly. The following results are based on the mean calculations from the remaining eight participants, some of whom did not score all the phases. Figure 7 further illustrates the differences in material quality evaluations among sample box types, serving as a visual representation of the raw data shown in Figure 6. These findings reveal potential opportunities and obstacles associated with each sample box type, providing valuable insights into the diverse properties of these BC-based textiles and potential applications. Figure 7 visually depicts the variations in material quality evaluations



**Figure 6**

Overall mean property scores from all stakeholder survey results. The radar chart highlights the mean score for each property across all sample box types collected from the stakeholders ( $n = 8$ ). General trends for the kombucha biomaterials demonstrate uniform means results for each described property. Created with RStudio (2022.12.0 + 353) (Source: Authors' own images).



**Figure 7**

Kombucha biomaterial property radar chart of means scores. Each property was ranked 1–5 based on “poor” to “excellent” quality by the stakeholders ( $n = 8$ ). The higher the score, the further the point is placed from the center of the radar chart to visually depict the variation in scores for each sample box type (named as group 1–5). Created with RStudio (2022.12.0 + 353) (Source: Authors’ own images).

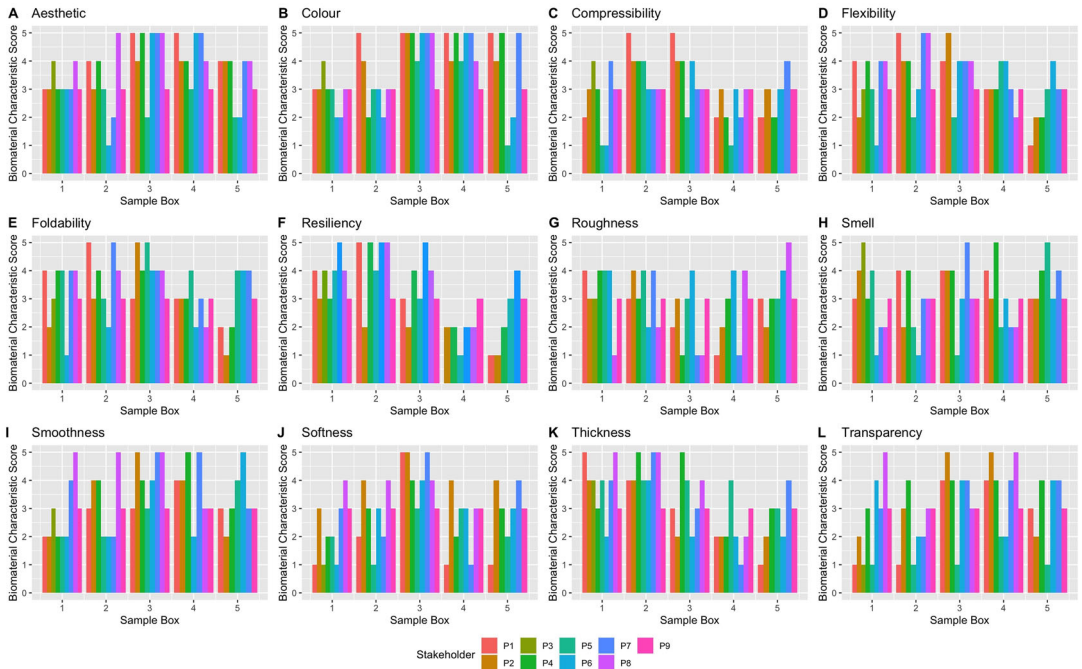
among different sample box types. Figure 8 provides a detailed bar chart illustrating the raw data collected from the stakeholders for the cellulose biomaterial’s property survey.

## Discussions

### *Interpretation of Results and Sustainable Potential*

The ‘Designing with Bacterial Cellulose Pilot Study’ explores innovative and sustainable textile alternatives rooted in natural systems. Through leveraging the outcomes of the kombucha brewing process, specifically the BC produced, the study introduced modifications in the culturing protocol. This approach led to a diverse array of BC products, which showcased subtle yet meaningful variations in their physical and visual attributes when different tea types and sugar sources were utilized.

These experiments highlighted BC’s versatility and sustainability, particularly in the context of Vietnam. The study revealed BC’s capacity to adapt to various ingredients and conditions, indicating its potential to contribute to a range of applications from sustainable fashion to eco-friendly packaging. The findings suggest BC’s role in



**Figure 8**

Bar chart of raw data collected from the stakeholders ( $n=9$ ) for the cellulose biomaterial’s property survey. Each stakeholder scored the sample box collection 1 through 5 based on “poor” to “excellent” quality. Plots a to L individually present the survey result data, including the stakeholder removed from the preceding figures which exclusively reported ‘average’ for all samples of all properties. The color-coded key identifies corresponding stakeholders to their survey results. Created with RStudio (2022.12.0 + 353) (Source: Authors’ own images).

potentially reducing the environmental impact across various industries within Vietnam.

**Comparison with Previous Research**

Acknowledging the context within broader research on BC, this study adds to the growing body of evidence showcasing BC’s versatility and ecological benefits in diverse settings. It aligns with previous findings, underscoring BC’s potential for sustainable development (Provin et al., 2021; Kamiński et al., 2020; Chan et al., 2017; Araújo et al., 2015). Tailoring BC production to leverage local resources and preferences represents a significant step towards enhancing its application in Vietnam, contributing to the global dialogue on sustainable material innovation.

**Conclusion**

This research investigated BC as a viable sustainable textile material in Vietnam. Employing a comprehensive methodology that included experimentation, stakeholder feedback, and the integration of

traditional knowledge, the study uncovered insights into BC's versatility and adaptability.

Building upon these foundational findings, the study has not only confirmed the viability of using local food sources for the cultivation of BC but has also highlighted its versatility and adaptability in various design contexts. The engagement with stakeholders revealed a broad acknowledgment of BC's potential, underscoring its suitability for innovative applications beyond the conventional uses. Stakeholder feedback emphasized the importance of further exploring BC's functional and aesthetic properties, suggesting that future research could focus on enhancing its drape and breathability to better align with traditional textile standards.

Moreover, the study uncovered valuable opinions regarding the integration of BC into the local economy and its role in promoting environmental sustainability. Stakeholders expressed enthusiasm about the possibility of incorporating BC into local production processes, noting its potential to foster economic development while reducing environmental impact. This aligns with global sustainability goals and reflects an increasing trend towards embracing biodegradable and renewable resources in industrial applications.

The implications of these findings suggest that BC could serve as a new sustainable material development in Vietnam and other similar contexts, potentially revolutionizing industries that are currently dependent on less sustainable materials. Additionally, the study's methodology, combining material experimentation with stakeholder evaluation, provides a replicable model for similar research initiatives elsewhere, offering a framework for engaging with local communities and industries to tailor material development to meet specific regional needs.

### **Key Findings**

The study demonstrated BC's potential for customization to local resources and preferences, offering a variety of bio-based materials with unique properties. The variation observed with local tea types and sugar sources highlights BC's adaptability, affirming its suitability for sustainable material production in Vietnam.

Feedback from stakeholders underscored the biomaterials' consistent quality and potential for diverse applications, from fashion to packaging. Notably, the materials' visual appeal and certain physical properties were identified as strengths, offering valuable avenues for design applications.

Incorporating traditional drying techniques and field research not only enriched the study's methodology but also brought together scientific exploration with local traditions, expanding the scope for sustainable material production, and enhancing the cultural relevance of the research.

### ***Implications for Sustainable Material Production***

The study's implications transcend laboratory boundaries, suggesting BC's role in advancing sustainable material production. Envisioning a future where BC is integral to reducing plastic usage in Vietnam, the research aligns with sustainable development goals, particularly in promoting responsible consumption and climate action (SDGs 12 and 13).

Furthermore, the findings are relevant globally, where the demand for eco-friendly materials is rising. By tailoring BC production to local ecosystems and cultural practices, the study paves the way for sustainable solutions that resonate across different communities, offering a model for integrating traditional knowledge with modern material science in pursuit of environmental sustainability.

### ***Limitations and Future Directions***

This research, while pioneering in its exploration of BC as a sustainable material in Vietnam, acknowledges its limitations. A notable constraint is the relatively small sample size of stakeholders engaged for feedback. The insights from a diverse panel of experts were invaluable, yet a broader stakeholder engagement could enhance the depth of understanding regarding BC biomaterials' potential applications and challenges. The study predominantly utilized qualitative methods to evaluate the biomaterial properties through stakeholder feedback. Future endeavours could extend to more comprehensive quantitative analyses, examining the mechanical, thermal, and structural characteristics of BC-based textiles in detail. Furthermore, assessing the scalability and economic viability of BC production on a larger scale within Vietnam presents a critical area for subsequent research.

This project marks a significant initial step towards uncovering BC's sustainability potential within the region. The adaptability in BC production methods, informed by multidisciplinary stakeholder insights, underscores the biomaterial's promising role in fostering sustainable design practices and eco-conscious industries in Vietnam and potentially, on a global scale.

In closing, this study underscores the importance of ongoing exploration and collaborative efforts. Future investigations will explore the quantitative aspects of BC-based textiles, aiming to broaden their application spectrum. Addressing the challenges of upscaling production and evaluating economic feasibility are pivotal for the material's practical adoption.

In essence, this research constitutes a vital stride towards a sustainable and environmentally friendly future in material production, both within Vietnam and internationally. By leveraging BC's capabilities and combining them with traditional knowledge and stakeholder feedback, the ambition is to contribute to a greener world—one BC sheet at a time.

## Disclosure Statement

The authors report there are no competing interests to declare.

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## ORCID

Donna Cleveland  <http://orcid.org/0000-0002-8223-7663>

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