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THE STATE OF PLAY: SYMBIOTIC CULTURE OF BACTERIA AND YEASTS (SCOBY) IN TEXTILE INDUSTRY

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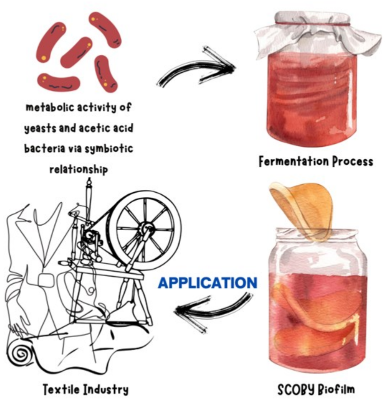
Graphical abstract



Abstract

The fermentation of Kombucha tea produces SCOBY, or Symbiotic Culture of Bacteria and Yeast, as a result of the interaction between bacteria and yeast. In order to fully explore the potential of employing this cellulose as a viable raw material in many applications of industry, numerous studies on the Kombucha SCOBY are now being done. According to studies, *Zygosaccharomyces* and *Acetobacter xylinum* are the most frequent bacteria found throughout the SCOBY fermentation process. At the air-liquid interface, these microorganisms help produce cellulose fibrils extracellularly, resulting in a biofilm. An overview of the favourable conditions for SCOBY manufacture is provided in more specific, as well as the aspects that may influence the product, and its suitability for textile and fashion sector applications is appraised. The advantages of this biofilm are being explored, including in several industries especially in textile and fashion industry. The microbial consortium's tea fermentation process was able to demonstrate an increase in specific biological activities that had previously been researched. However, there are some limitations in the applications of SCOBY in the textile that need to be highlighted. Thus, this review focuses on the SCOBY properties, challenges and potential available to make it feasible in textile industries.

Keywords: Kombucha, SCOBY, *Zygosaccharomyces*, *Acetobacter xylinum*

Abstrak

Penapaian teh Kombucha yang menghasilkan SCOBY, atau *Symbiotic Culture of Bacteria and Yeast*, adalah hasil daripada interaksi antara bakteria dan yis. Untuk melihat potensi penggunaan biopolimer ini sebagai bahan mentah yang praktikal dalam industri, pelbagai kajian mengenai Kombucha SCOBY sedang dijalankan pada masa kini. Menurut kajian, *Zygosaccharomyces* dan *Acetobacter xylinum* adalah yis dan bakteria yang lazim terdapat dalam proses penapaian SCOBY. Dalam medium cecair-udara tertentu, mikroorganisma ini membantu menghasilkan jaringan selulosa secara ekstraselular dan membentuk biofilem. Sorotan mengenai keadaan yang sesuai untuk penghasilan SCOBY diterangkan dengan lebih terperinci, termasuk aspek yang boleh mempengaruhi hasil dan kesesuaian dalam sektor tekstil dan fesyen. Kelebihan biofilem ini sedang dikaji, terutamanya dalam beberapa industri, khususnya dalam industri tekstil dan fesyen. Proses penapaian teh dengan konsortium mikrob menunjukkan peningkatan aktiviti biokimia tertentu yang sebelum ini telah dikaji. Walaubagaimanapun, terdapat beberapa kekangan di dalam penggunaan SCOBY, khususnya industri tekstil yang perlu diberi perhatian. Oleh itu, sorotan literatur ini memberikan tumpuan kepada ciri-ciri, cabaran dan potensi SCOBY sebagai bahan mentah praktikal dalam industri tekstil.

Kata kunci: Kombucha, SCOBY, *Zygosaccharomyces*, *Acetobacter xylinum*

1.0 INTRODUCTION

The evolution of food and beverages day by day is evolving due to the needs of the communities. There are various meals and drinks that are frequently consumed for people presumed and confirmed health benefits, in addition to countering basic hunger, fullness, and flavor. A dried tea leaves extract that is mixed up with hot water is one of the herbal drink's medicines for stimulating and purifying properties. The most often consumed processed beverage is tea. The commercially available teas include green tea and oolong tea. Besides, nowadays, tea is the most popular beverage in countries such as China, Egypt, Myanmar, India, Germany and other countries.

Kombucha tea is a traditional beverage, and it is also well known as fungus tea as it is synthesized by the association between eukaryotes cells, which are Symbiotic Culture of Bacteria and Yeasts (SCOBY) through fermentation process. Kombucha is a fermented tea that comes from the same family as yogurt, vinegar, and cheese, which have been consumed for generations for their health advantages. Therefore, fermented Kombucha have their own nutritious components like organic acids, minerals, vitamins, proteins, polyphenols, and a variety of anions that give benefit to human health [1]. These traditional beverages, when freshly prepared, the taste of the drinks is like apple cider with a hint of sweetness. These beverages are made by steeping a tiny amount of plant material in freshly boiled water and the most popular types of tea are black and green. In the making of Kombucha, there are three major ingredients that are needed to brew it, which are tea, water and sugar. The product that produces by the fermentation of Kombucha is cellulose or it is also called as biofilm. The characteristic feature of this biofilm is a cellulose pellicle like on the air-liquid surface of the fermentation medium, which consists of lactic acid bacteria (LAB), acetic acid bacteria (AAB) and yeasts. This formation of cellulose pellicle occurs from the metabolic activity of chosen stains of AAB [2]. As fermentation is one of the oldest processes for producing probiotic beverages and it features presence as a low cost in the energy saving strategy [3], it has been utilized widely under favorable conditions. There are many factors that influence the cellulose pellicle formation such as the types of substrates used, duration, surface area and temperature [4]. To achieve a quality end-product, these fermentation conditions must be carefully monitored in terms of SCOBY sensitivity.

The SCOBY is used to ferment the media that contains tea extracts and sugar sources for 7 to 10 days [5], in a three-dimensional cellulosic zoogleal mat. Zoogleal mat is a cellulose biofilm or mother SCOBY. Fermented food is mainly produced by microorganisms that alter the taste, nutritional content, and digestion of the original food [6]. Basically, SCOBY biofilm will be arisen at the upper part of the fermented tea in the beaker (Figure 1). The typical SCOBY production process is conducted in a glass beaker that filled up with an acidified sugar black tea and covered up with paper cloth to make sure the fermentation process between the bacteria and yeasts occurs in the media. After 3 days, the daughter SCOBY will be formed at the air-liquid layer of the Kombucha and after several days, the daughter SCOBY will be enlarged to form new cellulose pellicles, which are mother SCOBY. Besides, at the upper part of the mother SCOBY, there will be the initiation of a new daughter SCOBY. The mother SCOBY will sink to the bottom of the media and the new daughter SCOBY will rise to the upper layer of Kombucha.

Figure 1 The Formation of Mother and Daughter SCOBY (Modified and adapted from May *et al.* [7]

While growing and multiplying in the sweet tea culture medium, there are microbes that would produce a variety of beneficial chemicals. In the formation of SCOBY, bacteria (*Acetobacter xylinum*) and yeasts play an important role in the fermentation process. The fermentation of sugar by yeasts and bacteria results in the development of ethanol and acids, which are natural preservatives that give fermented beverages an extended shelf life. The SCOBY contains various yeasts and the common yeast population that obtains in the fermentation process are *Zygosaccharomyces* and *Saccharomyces*. *Zygosaccharomyces* is a genus that can be found in both pellicle and broth frequently. Yeast cells in the culture media tend to sink to the bottom, with a few yeast cells becoming trapped in the cellulose produced by the bacteria near the surface layer.

The biofilm's characterization investigations revealed that SCOBY possesses a variety of fascinating physical, chemical, and biological properties that can be utilized for a variety of applications. Despite this fact, even more studies have been done on SCOBY production, however, there is a lack of information that focuses on SCOBY production using conventional and non-conventional substrates in the industrial applications, mainly in the fashion and textile industry [8].

In the production of apparel, the structure and properties of the SCOBY need to be highlighted before use. SCOBY has unique properties that give many branches of opinion in terms of hydrophilic features of SCOBY. More studies on the strategies of SCOBY in the textile industry need to be done by treating the properties of the SCOBY with new factors to make it more applicable in the textile industry. Thus, the objective of this review is to elucidate the SCOBY production substrates and to review the applications of SCOBY in textile industry.

This review would be essential to understand the current progress on SCOBY production, and the attempts on SCOBY textile applications for acquiring a better improve the SCOBY feature, especially for dyeing potential and finishing. Besides, the utilization of conventional and non-conventional substrates also show the ability of numerous substrates to reduce the utilization of high-cost conventional substrates to prove the usefulness of production of SCOBY in textile industries and leads to low production cost.

2.0 SYMBIOTIC CULTURE OF BACTERIA AND YEASTS (SCOBY)

Originally, the traditional drink was produced by fermenting sweetened black tea (*Camellia sinensis*). However, other teas also can be used to prepare these Kombucha SCOBY. The cellulose pellicle that obtains after the fermentation process is due to the association of bacteria and yeast. This cellulose pellicle is called SCOBY, which is an association of symbiotic culture of bacteria and yeast. In the fermentation process of SCOBY, there are many types of bacteria and yeast that can be found (Table 1).

Table 1 Microorganisms of SCOBY [9]

Bacteria	**Yeast**
Acetobacter sp.	*Brettanomyces lambicus*
Acetobacter aceti	*Brettanomyces claussenii*
Acetobacter pasteurianus	*Brettanomyces custersii*
Acetobacter nitrogenifigens	*Candida kefyr*
Acetobacter peroxydans	*Candida krusei*
Bacterium gluconicum	*Candida stellata*
Enterobacter cancerogenus	*Candida stellimalicola*
Enterobacter cloacae	*Candida tropicalis*
Enterobacter ludwigii.	*Candida parapsilosis*
Gluconacetobacter kombuchae	*Debaryomyces hansenii*
Gluconacetobacter europaeus	*Dekkera anomala*
Gluconobacter saccharivorans	*Dekkera bruxellensis*
Gluconobacter oxydans	*Eremothecium cymbalariae*
Komagataeibacter xylinus	*Halomonas* sp.
Komagataeibacter rhaeticuse	*Sporopachydermialactativor*
Komagataeibacter hansenii	*Torulaspora delbrueckii*
Lactobacillus fermentum	*Torulopsis* sp.
Oenococcus oeni	*Zygowilliopsis californica*
	Zygosaccharomyces californica
	Zyfosaccharomyces bailii

Basically, acid-tolerant microorganisms like *Dekkera* sp. and *Candida stellata* were discovered during acetic fermentation, while osmotolerant fermentative bacteria like *Zygosaccharomyces* sp., *Torulaspora delbrueckii*, and *Schizosaccharomyces pombe* were present at the beginning of fermentation [9]. Aside from that, bacteria were more frequently discovered and more diverse than yeast in the fermentation culture than in the biofilm, according to research on bacterial correlation and its biochemical structure. In the fermentation culture, eight bacterial communities were discovered to be prominent, including *Lactobacillus fermentum, Gluconacetobacter saccharivorans, Acetobacter aceti, Gluconacetobacter europaeus*, and *Arxula adeninivorans* [10].

Acetobacter xylinum

The types of bacteria and yeasts are important in the production of different properties of SCOBY in industry. *A. xylinum* is the main bacteria that produces cellulose biofilm. It's a Gram-negative, motile and presence in a rod-shaped and aerobic. *Acetobacter* species are important in creating a cellulose network that serves as the physical foundation for the symbiosis' development. Basically, cellulose biofilm is obtained from the lignocellulosic biomass of plants. However, it also can be synthesized by some bacteria like *A. xylinum*. The special features that make bacteria cellulose widely used compared to the plant cellulose are that the cellulose produces 100 times smaller nano-fibrils networks, which can help in the limitation of liquid infiltration. Bacterial cellulose is a biopolymer composed of repeated D-glucose units that connected by β-1,4 glycosidic bonds. These play an important role to produce a highly request in the application of industries. Besides, bacterial cellulose has several advantages compared to plant-based cellulose in terms of the high purity, liquid loading capacity, mechanical strength, crystallinity, non-toxicity, sustainability, biocompatibility, and biodegradability are all important factors to consider [11].

The oxidation of glucose to gluconic acid, which is found in the liquid phase, is a special biochemical activity of *A. xylinum* and another metabolic pathway produces microbial cellulose, which is used to form the biofilm that persists to the surface of the liquid. The process begins with the creation of uridine diphospho-glucose (UDPGlc), which is a cellulose precursor (Figure 2), followed by the polymerization of up to 200,000 glucose residues per second into β-1,4-glucan chains by each single *Acetobacter* cell.

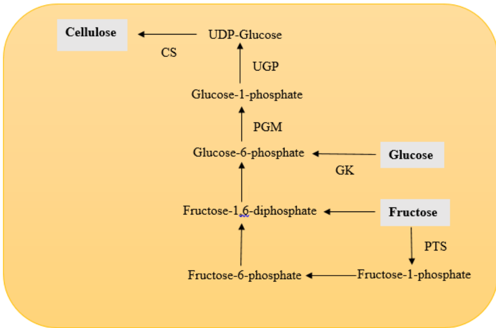


Figure 2 Biochemical Pathway for Cellulose Synthesis by *A. xylinum* (Modified and adapted from Chawla *et al*. [12]

This process of cellulose production has its benefit of being able to create cellulose under regulated conditions from a variety of carbon sources, including glucose, ethanol, sucrose and glycerol [13]. In general, during the fermentation process occur (Figure 3), the yeast plays its role to produce the product of fermentation which are glucose, fructose, and carbon dioxide that results in the releasing of gas and the appearance of carbonation [14]. In a nutshell, the fermentation process happens when ethanol is formed as a result of yeast metabolising sucrose, and these bacteria use glucose oxidase enzymes to oxidise the ethanol that the yeasts produce to form organic acids [3]. Alcohol is converted to acetic acid by the acetic acid bacteria, although the production of gluconic and glucuronic acids is also important. Because the biofilm portions of the upper cellulose layer receive more oxygen from the bacteria than the liquid broth portions, the concentration of acetic acid there is higher.

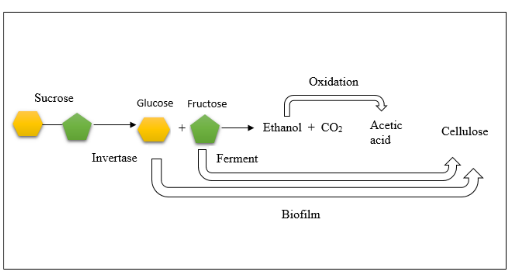


Figure 3 Main Metabolic Activity of Kombucha tea (Modified and adapted from Markov *et al*. [15]

Acetic acid could be utilized to promote cell growth by participating in the Krebs cycle, which results in the creation of carbon dioxide, or as a precursor to produce cellulose. Hence, *Acetobacter* could polymerize glucose residues to generate a bacterial cellulose mat that supports microbial growth [13]. They also showed the presence of a competitive nutritional profile between the glucose and acetic acid. The bacteria in the liquid that produce cellulose mostly by utilizing all the dissolved oxygen. Bacterial cellulose is a function to produce an extracellular form of fibrils, which is linked to the bacterial cell. For extruding cellulose out of the membrane, each single cell is composed of 50 and 80 pores with a diameter of 3.5 nm.

Zygosaccharomyces

commonly a eukaryotic microorganism that live mainly in water, soil, air and on fruit surfaces. There are several species of yeasts that can be used to produce Kombucha, which are *Candida boidinii, Zygosaccharomyces rouxii, Dekkera bruxellensis*, and *Saccharomyces cerevisiae* [9] (Table 2).

Table 2 The different species of yeasts found in the fermentation of Kombucha (Modified and adapted from Villarreal-Soto *et al.* [13]

Genus	Species	Sources(s)
Breattanomyces	*Brettanomyces intermedius* *Brettanomyces bruxellensis*	Coelho *et al*. [16] Dutta & Paul [3]
Candida	*Candida boidinii* *Candida famata* *Candida guilliermondii* *Candida obtuse*	Coelho *et al*. [16]
Dekkera	*Dekkera bruxellensis*	Antolak *et al*. [17]
Saccharomyces	*Saccharomyces cerevisiae* *Saccharomyces bisporus*	Antolak *et al*. [17] Coelho *et al*. [16] Dutta & Paul [3]
Zygosaccharomyces	*Zygosaccharomyces rouxii* *Zygosaccharomyces bailii*	Coelho *et al*. [16] Dutta & Paul [3]

In comparison between yeasts to other microorganisms such as lactic acid bacteria, yeasts are not extremely nutritionally demanding. The presence of fundamental substances such as fermentable carbohydrates, amino acids, vitamins, minerals, and oxygen aids their growth. However, the common genus of yeasts that are present in the fermentation of SCOBY is *Zygosaccharomyces*. It plays an important role as an osmophilic yeast in the fermentation of Kombucha due to its strong endurance to osmotic stress. This genus is classified as a rotting microbe and it can survive in a challenging environment with high sugar levels such as in the making of wine and, also fermented SCOBY process.

According to Xiang *et al*. [18], in the presence of organic acids, low oxygen levels, and high concentrations of approved preservatives, this *Zygosaccharomyces* genus may also survive in extreme environments. However, the growth of yeast cells was very slow compared to bacteria. The features of these yeasts are an ellipsoid, non-motile, with round, oval shapes and undergoes anaerobic respiration.

In these fermentation processes, sucrose is the primary carbon source. The yeast enzyme invertase catalyzes the hydrolysis of sucrose to glucose and fructose, resulting in the production of ethanol through the glycolysis pathway. However, *Saccharomyces* prefers glucose while *Zygosaccharomyces* genus yeast is prefer to fructose. The acetic acid bacteria will form gluconic acid from the glucose and acetic acid from ethanol. The presence of acetic acid induces yeast to form ethanol, which was subsequently utilized by acetic bacteria to grow and generate more acetic acid. The *Acetobacter* convert the ethanol that is produced by yeasts to acetic acid. The enzymes alcohol dehydrogenase and dehydrogenase will conduct this activity by entering Krebs cycle, which causes water and carbon dioxide to be produced. Hence, the final product of fermented Kombucha is ethanol, gluconic acid, and acetic acid.

3.0 SUBSTRATES IN SCOBY PRODUCTION

The Production of Kombucha SCOBY

Kombucha traditionally is produced by using green, oolong or black tea. The black tea that has been treated with sucrose for sweetening is the best substrate for Kombucha fermentation. However, green tea is the most popular tea compared to the black tea. According to Zhao *et al*. [19], green tea contains the highest quantity of phenolic chemicals than yellow, oolong, dark, black, and white teas. Besides, green tea also has the most powerful antioxidant effects of all the tea that have been studied. The process of making Kombucha begins with the infusion of tea. Making a tea base and adding sugar, which will work as a substrate for the fermentation between bacteria and yeasts, is how kombucha is formed [5]. The reported amounts of tea and sugar for brewing kombucha are listed in Table 3.

In the fermentation process, 50 g of sucrose will be dissolved in 1L of boiling water (Figure 4). Boiled it for 10 minutes. Fifty gram is the best amount of sugar to undergo the Kombucha fermentation process. After that, 5g of tea leaves or tea bags was added into the solution followed by stirred, brewed, and filtered [3].

Table 3 The amounts of tea and sugar in the preparation of Kombucha [16]

Tea	Sucrose	References
0.5%	5%	Jayabalan *et al*. [20]; Leal *et al*. [5]
5%	10%	Santos [21]
0.8%	8%	Gaggia *et al*. [2]

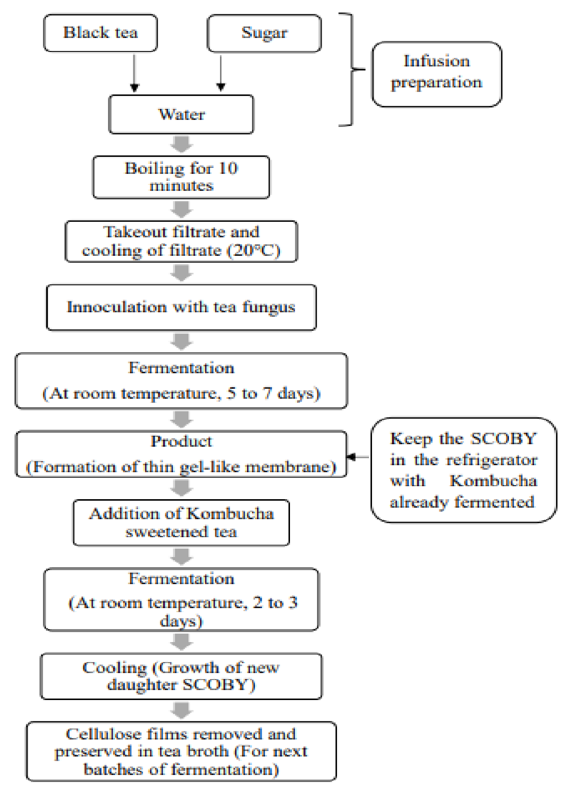


Figure 4 The Making of Kombucha and SCOBY (Modified and adapted from Kumar & Joshi [22]

In the production of SCOBY with different quantity of yield, it is required different amounts of tea and sugar that need to be added in the fermentation process. Next, after 5 minutes, the solution will be screened. Before inoculating with 24 g of SCOBY, the mixture is chilled at 20°C. This step is important to prevent the inactivation of microorganisms [23]. In industrial processes, large surface areas in the fermentation tanks are enabled for the exchange of cultures, which are necessary to produce subsequent fermentation [1]. After that, the SCOBY solution is transferred to a heat sterilized beaker. To reduce the pH, 200 mL of previously fermented Kombucha beverage is added.

Unfortunately, there is the growth of unwanted contaminating bacteria during the fermentation process. This risk was prevented by the lower pH, which is at pH 4.6 to inhibit the growth of contamination. This is because the fruit flies from the genus Drosophila are drawn to acidic sweetened liquids and frequently contaminate them. Thus, the beaker will be covered up with a paper towel.

After only a few days at room temperature, a daughter SCOBY develops from the injected mother SCOBY and bacteria suspended in the broth. It develops in a physically translucent, thin gel-like membrane that floats on top of the mother SCOBY and can occasionally be connected to it. In around 14 days, the SCOBY grows as a new layer that builds up on top of itself, reaching a thickness of 8 to 12 mm (Figure 5). At this point, distinct gas bubbles and a fermented odor can be detected. Besides, it has shown that there are different thickeners of cellulose biofilm if the duration of fermentation process were extended. The mother SCOBY tends to descend to the bottom of the fermenting beaker as fermentation progresses.

By the 10th to 14th day of incubation, the daughter SCOBY had grown and covered the liquid's surface, with a pH as low as 2.0. It is depending on the SCOBY composition and the rate of fermentation; the period may vary. Subsequently, the growth of the new daughter SCOBY was observed. After the new cellulose pellicle has been generated, the cellulose films should be removed at the end of the initial fermentation and preserved in a tea broth for next batches of fermentation.

Figure 5 Layers of SCOBY during the first day of fermentation, 7 days of fermentation and after 3 weeks of fermentation (Modified and adapted from Soares *et al*. [24]

Non-conventional Substrates in SCOBY Production

The recent technology and progress have been widely explored by researchers in terms of SCOBY substrates used in the application of industry. There are two types of substrates that promote the production of Kombucha SCOBY in the industry. Firstly, non-conventional substrates [25]. These substrates can be used in the making of SCOBY by using by- products and waste products. Fruits and plant waste raw materials, as well as their by-products contain a higher concentration of bioactive components such as polyphenols, flavonoids, caffeine, carotenoids, creatine, and polysaccharides, that are unique and have their own beneficial properties [26].

Molasses

The organic carbon sources like glucose and acetate are typically costly. Despite this fact, a low-cost medium supplement may be made from a low-cost industrial by-product, such as sugarcane molasses. Molasses substrates which can be replaced the sugar is produced as a by-product of the sugar refining process. Sugar beet molasses may be an appealing source of sugar due to its low cost and the presence of several beneficial components such as minerals, organic compounds, and vitamins which give more advantages to the fermentation process. Molasses contains a considerable level of reducing sugars such as glucose, fructose, and other carbohydrates. Its presence of 50% total of sugars, which is primarily sucrose [27]. Basically, molasses which is from sugar cane and sugar beet is one of the substrates that is popularly used in the fermentation industries. Besides, molasses from beets and canes is also commonly used in animal feed and the product is widely used over the world as a by-product of sugar extraction. The total acidity, biomass production and lactic acid content were higher in sugar beet molasses fermented Kombucha, while only the acetic acid content was higher in sucrose fermented Kombucha. Molasses had more antioxidant qualities compared to the Kombucha that is made from white sugar and the addition of sugar beet molasses in the manufacture of Kombucha has been shown to boost the phenolic components [28].

Furthermore, it is found that molasses as a better composition, they are good fed to ruminants as a source of energy [29]. According to the Piasecka *et al*. [27], sugarcane molasses has been reported as a carbon source for the generation of biomass for biodiesel, which are from *Botryococcus braunii, Chlorella vulgaris, Chlorella sorokiniana, C. zofingiensis, Haemotococcus pluvialis, Scenedesmus obliquus*, and *Spirulina platensis* up to now [27].

Hence, from these alternative raw materials, the final product of fermentation has a higher level of antibacterial and antifungal action. Several researchers have advocated using industrial by-products [30] and fruit and vegetable waste [31] as an alternate substrate for Kombucha fermentation to minimize the cost of raw materials during scale-up. The tea leaves that have been used previously can be dried and reused. According to Laureys *et al*. [32], and Villarreal-Soto *et al*. [13], tea leaves are a suitable substrate for fermenting Kombucha. The used tea leaves are a viable option for obtaining a high yield at a low cost of manufacturing [4]. It has been proved that various research used Kombucha cultures with grape juice [33], *Eucalyptus camaldulensis*, and *Litsea glaucescens* effectively by generated it from fermented plant-based beverages.

Chamomile Tea Leaves

There are a few other teas that can be used to replace the original tea for the fermentation process of SCOBY. Chamomile or the scientific name is known as *Chamaemelum nobile* or *Anthemis nobilis*. It is a flowering plant that native to Europe and North America. Chamomile tea is one of the herbal teas that can replace the original tea leaves. It is well known that chamomile tea leaves presence of phenolics and flavonoids components in which it is extremely bioactive components. The studies have shown that phenolic compounds are responsible for giving benefits to health as they are found in herbal plants [34; 35; 36). According to Al-Dabbagh *et al*. [37], chamomile extracts could inhibit tumor angiogenesis in a dose-dependent way. These may give a lot of advantages to the medical group especially to the cancer patients. In addition, in the preparation and fermentation process of Kombucha chamomile, there are using the same steps as in the preparation of Kombucha black tea. However, the chamomile flowers are used to replace the black tea in this fermentation process.

Conventional substrates will used others than traditional substrates such as green tea leaves, oolong, and black tea leaves to achieve the production of SCOBY. Using different substrates may influence the production of SCOBY [38].

Conventional Substrates

The conventional substrates also can promote the growth and metabolism of microorganisms resulting in a higher overall yield of SCOBY. The conventional substrates like sugar is used in SCOBY fermentation. In general, SCOBY fermentation will use 50 grammes of sugar per litre of tea is employed to ensure a good fermentation. The yeast will digest glucose and fructose into ethanol, carbon dioxide, and glycerol. The ethanol is then converted into acetic acid by acetic acid bacteria (AAB). The AAB stimulates the yeast to produce ethanol [39].

3.0 FACTORS AFFECTING SCOBY PRODUCTION

However, to conduct the SCOBY fermentation, there are numerous biological, chemical, and physical parameters that must be optimized. They are the duration, pH, substrate, source, inoculum viability, temperature, and cell growth because these factors may influence the SCOBY synthesis.

Duration of Fermentation

Fermentation period can affect the activities of bacteria in the fermentation process. The range for the optimal period for the fermentation process is between 7 to 15 days. When the fermentation period increases, the carbon dioxide will be accumulated between broth and biofilm resulting in limited nutrition transfer and starvation. The taste of the Kombucha is slightly sweet and mildly acidic. However, due to its complex growth conditions, the bacterial and yeast cell counts will be raised until day 14 and subsequently dropped. Acid-sensitive microbial cells in the biofilm were killed and are released into the tea broth, which resulted in a drop in SCOBY weight after a specific day [40]. These proved that the longer time of fermentation, the higher level of organic acid will be produced during the fermentation process. Unfortunately, although much of the antioxidant activity is found highest during incubation time, the longest fermentation period is not suggested. This is due to the formation of organic acids in which it could reach harmful levels if consumed directly. Furthermore, the production of carbon dioxide may begin to accumulate between biofilm and broth contact that will obstruct the nutrition transmission and result in a deprived environment.

According to Coton *et al*. [9], the studies have shown that the evolution of Kombucha tea bacteria communities from industrial production over time is during day 0, 2, 4 and 8. They discovered that on day 0, most of the acetic acid bacteria (AAB) were more prevalent in biofilms than in liquid broth. After 8 days, the AAB will be reached at equilibrium level. However, in contrast to the yeast species, it appears to be stable in both phases throughout the fermentation. Thus, these have shown that time required for biofilm may influence the final growth of cellulosic pellicle.

Types and Concentration of Tea Leaves and Sugars

The types and concentration of tea leaves used in the making of fermented Kombucha are the important components. It is very important to choose the right raw materials or substrates for the fermentation process of the SCOBY such as the types of tea leaves used, for instance, green tea, black tea, oolong tea leaves. Besides, the sugar that acts as a substrate that can be used in the making of Kombucha SCOBY is glucose, sucrose, and others.

In the comparison between fresh tea leaves and used tea leaves, mostly the industry is going to implement used tea leaves as it gives a lot of benefit to human health and the expenses of creating SCOBY on a large scale. According to Gargey *et al*. [39], the waste tea leaves yielded 210 g/L cellulose when employed at a concentration of 4 g/L, which is higher than black tea. Nonetheless, when there is an increased level of polyphenol due to the higher concentration of tea, the production of biofilm will decrease because of the inhibition by Gram-negative bacteria. Tea leaves that have been utilized as a raw material are also being regarded as a viable option for achieving high yields at a low cost of manufacturing [4].

Tea components can affect the predominance of bacteria in Kombucha tea as fermentation is also dependent on the type of infused tea. Based on the types of tea leaves used, the black tea has a milder flavour, more nitrogen and purine compared to green tea. However, when there are additions of tannins into the green tea, it may give a slightly bitter flavour [9; 41). The maximum concentration of acetic acid, which is 9.5 g/L was found in green tea Kombucha on the 15th day of fermentation. After that, it began to decline gradually. On the 12th day, black tea with 2.33 g/L and green tea with 1.73 g/L had the highest levels of glucuronic acid and the primary organic acid in Kombucha responsible for its detoxifying action. It is widely known that the importance chemicals that needed to grow the SCOBY, the culture medium must have a carbohydrate component that act as a carbon source and the tea extract will be act as a nitrogen source for it to be digested in the fermentation process for the cellulose formation and microbial development. In addition, sucrose is the most common carbon source and when green tea leaves were chosen instead of black or oolong tea leaves, the yield production of the SCOBY will be higher.

After that, the types of sugar also may give impact to the production of Kombucha SCOBY. To form a high yield of cellulose pellicle, 90 g/L concentration is the great measurement of sugar for the optimum level. Besides, molasses, fructose, malt extract and brown sugar also have been used that act as carbon sources to replace sucrose. Molasses has a good potential as a low-cost alternative of sucrose and can produce a high yield of Kombucha cellulose compared to pure sucrose. On the other hand, malt extract possesses an inexpensive source of starch and contains various healthy bio-components like proteins, anions, cations, and vitamin B complex.

Temperature

The temperature for the fermentation process is very important because the unsuitable temperature process for the microorganisms may give a negative effect to the final production of cellulose pellicles. The optimum temperature for Kombucha SCOBY production is in the range of 20°C–50 °C. When the fermentation process is carried out above 60°C, the formation of cellulose pellicles will not exist due to the inhibition of bacterial growth and enzyme activity. This has been proved that SCOBY manufacturing was typically done at temperatures ranging from 27°C–34°C [4].

pH

pH is one of the important factors that need to be highlighted because it may influence the growth of the bacteria and the growth of SCOBY. The optimum pH that tolerable for microorganisms undergo fermentation process are in the range of 2.5 to 4 pH. The bacteria in the fermentation process, which is *Acetobacter* sp. able to grow well in pH ranges of 4 to 6.3, although it also can grow in lower pH ranges due to the presence beneficial of bacteria in a fermentation symbiotic relationship. According to Sharma & Bhardwaj [4], during the fermentation process, at pH 5.0, the moulds and other contaminants were observed on the surface area of the cellulose pellicles. However, at pH 6, only moulds grew between the nanofibers of Kombucha SCOBY.

4.0 TEXTILE FROM SCOBY

As SCOBY has been recognized as a useful raw resource with a variety of applications in different fields, it might be used as a potential biodegradable and biocompatible material. Hence, this has been proved by the usage of SCOBY in food supplement, packaging materials [42], medicinal applications [43], tissue engineering, metal ions removal [44], electronic [45] and textiles industries [46]. The uniqueness of its structure and properties makes it more sustainable in different ways in terms of the physical, chemical, mechanical, and biological. The biofilm of SCOBY has an ultra-thin fibrous network, which the formation of pores in smaller size that are important in absorptive, capable in ion exchange capacity, have an elastic property in wet condition besides, brittle and shrink property in dry condition due to the hydrophilic nature of bacterial cellulose [47; 48]. Moreover, these porous materials will be swollen even more by ultrasound and function as an enzyme that has the potential to support immobilization in industrial applications [49].

In textile industries, for the case of cellulose, studies have demonstrated that the material qualities must be adjusted before biosynthesis, in situ, which modifies the biophysical features that are already present [50]. The water holding capacity of the cellulose biofilm can be adjusted by using different combinations of growth medium, which changes the structural and functional properties of the SCOBY [51]. The arrangement of the fibrils and the high surface area per unit or mass can be determine the recommended characteristic of hydrophilic of biofilms and the ability of cellulose biofilm to retain water during the process occur [52].

The interesting properties of the biofilm molecules is the result are highly inflated in three-dimensional (3D) network with pore structures that can store up to 99% of water, allowing it to be used to create highly biodegradable tissue forms (51; 59). For the untreated SCOBY, the hydrophilicity is higher and shows an inherently high wettability. However, in the absence of hydrophobic treatment, it may limit the usefulness of these pellicles. According to Sederavičiūtė *et al*. [47] and Martins *et al*. [48], from the chemical properties of Kombucha SCOBY in terms of hydrophilic, the search for material dimension stability is important because the sample of the SCOBY can shrink while drying. Although the use of SCOBY in the textile industry adheres to the principle of minimal to zero waste, these products are restricted to designs for specific types of apparel such as cellulose-based clothes and wristband [45] and are complex to implement to traditional manufacturing of common apparel. It is well recognized that SCOBY may be used in a variety of ways. There are new options for combining it with organic products that have been investigated to retain its safety and quality besides extending its usable life [52].

Challenges in Textile Industry

The end result of microbial tea fermentation has been used to create microbial textile in the fashion sector. Although SCOBY has been investigated in the preparation, treatment, and manufacturing of apparel and accessories from biodegradable leather, its large-scale production remains a difficulty. [53]. The main issues that could be described in future research are treating tailored wettability and liquid-absorbing capacity of SCOBY. In addition, extensive research at molecular and biochemical research should be attempted to incorporate more innovative applications in fashion/textile industry.

Improved economics for employees will result from the opportunity for a new and sustainable textile production system to create jobs in a sector where none do so at the moment. By implementing a new and sustainable textile production system, waste generation will be reduced. This reduction in waste is expected to have economic benefits, such as cost savings and less of a burden on the community to manage and mitigate the negative impacts associated with waste disposal. This, in turn, could lead to improved economics for employees and the community as a whole [54].

Other challenge in SCOBY production such as the unflexibility of drying process is also important to be solved to preserve their final properties and ideal for commercialization. According to Domskiene and colleagues [55], is likewise susceptible to drying temperatures. They dried bacterial cellulose SCOBYs at room temperature to achieve the best deformation properties, however, the cellulosic film's qualities altered with time, potentially posing a durability problem. Another interesting finding by Ukrainian researchers reported that the constituent of microbes in SCOBY relied much on temperature changes, space vacuum and also UV radiation [56].

SCOBY can play a role for other materials in the textile area [57] and interior design materials [58]. Materials in fashion or textile industry must provide an ideal set of features, such as body fit, strength and comfort. Due to the SCOBY-cellulosic porous structure, hydrophilicity and hydrophobicity properties, these characteristic exhibits a challenge for some uses in the textile industry [59]. The textile industry and fashion industry are emerging and indirectly lead researchers and scientists to focus on biomaterials like SCOBY, bacterial cellulose and their features.

Since biomaterials offer biocompatibility, they can be tailored and considered as a value-added product [57], and represents important potential source of biopolymer [55]. For example, bio-couture manufacturing has been expanded by the designer, Suzane Lee, which aims to explore and investigate the compatibility of different textile biomnaterials of the production of textile [49].

A research on packaging is also favourable in textile sector and clothing. As reported by Patwa *et al*. [61], they elucidated hydrophobization process for membrane packaging, which involved storing in 40°C vacuum. Furthermore, integrating polylactic acid (PLA) and bacterial cellulose is also useful in contributing to textile industry. Another study conducted has integrated beewax with bacterial cellulose [62].

5.0 FUTURE PROSPECT

There are several alternative ways to alter the hydrophobicity and hydrophilicity of the SCOBY. By altering the hydrophobic and hydrophilic compositions of alkoxysilanes, a basic modification procedure adaptable for a variety of different porous materials was used to modify wetting behaviors. This study shows that by modifying the composition of alkoxysilanes in the hydrolysis process, it can easily change the wettability of the final membranes of the SCOBY. Besides, the limited dispersion of hydroxyl groups in non-polar fluids and polymer matrices is due to the hydrophilic character. As a result, hydrophobization is frequently utilized to increase the compatibility.

According to Song *et al*. [49], there are several functional compounds such as polyethylene glycol, silver nanoparticles, and zinc oxide, which have been employed to alleviate the problems of hydrophilicity. It has been proved that these types of materials could be included into three-dimensional BC matrices resulting in improved crystallinity, porosity, hydrophobicity, and mechanical characteristics. In this way, the similar properties of clothing fibers can be develop based on their significant importance in the fermentation process.

As biopolymers and biomaterials have been popularized for manufacturing, who knows what the future will hold for the textile and fashion industry. because designers learn just how easy the process is, it will make more reasonable to incorporate SCOBY into the designers' masterpiece. The impacts of the extensive use of a biodegradable and plant-based material on the environment would be remarkable.

The extreme fragility and hydrophilic features, among other characteristics, make it a difficult biomaterial to use in commercial goods, claim Dhar *et al*. (63). However, the disposal of textile waste has become a recent problem. Additional research on bacterial cellulose would be fantastic because the majority of textile waste is not biodegradable [45].

More alternative biodegradable materials may be used in the textile sector if the properties of bacterial cellulose are altered, for example, to address the problem of hydrophobicity. The textile industry has to find new sustainable materials, therefore delivering hydrophobicity must be in line with proposals to promote sustainability in this area. This issue increased investment. Therefore, it is obvious that more research is needed to determine whether cellulose SCOBY can be used in the textile industry and how best to do it.

Consequently, bioprocess engineers seek strategies that can be applied and expanded, rather than to produce authentic pieces. Interdisciplinary collaborations are indispensable in facing the complex challenge of sustainability. The results of this approach can be an intermediate stone to consumer products in upcoming future [64]. The main impact variables along the value-added chains of alternative leather manufacturing include the production of tea and the brewing of PLA-biopolymer and PU coatings.

Market acceptance and the scaling up of by-products, as well as the kinds of coatings and/or impregnation agents used to boost the durability of the substitute materials, are important factors that must be carefully taken into account.

6.0 CONCLUSION

SCOBY is a developing biomaterial used in the production of textiles and fashion applications, according to the assessment. In order for the process and the final product to be able to meet the unique requirements of the textile industry, further research should concentrate on enhancing kombucha industrial processes by optimising and elucidating specific features, including product uniformity.

This mini review also highlights that conventional and non-conventional substrates are crucial to synthesize the high production of SCOBY. Plant extracts have sparked a lot of curiosity when it comes to tea beverages such as Kombucha because of their many uses. The usage of cellulosic SCOBY produced via Kombucha fermentation process as a sustainable option for use in the textile and fashion industries has been shown to be promising.

To determine the optimum fermentation conditions, several reactor parameters must be considered in which it may influenced the SCOBY production. Since SCOBY consists of cellulosic features of bacterial cellulose, its mechanical and chemical properties make it a good prospect for textile use, however, extensive study is required to tune hydrophilicity feacture to make it fit and useful in textile industry.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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