Engineering and Technology Journal e-ISSN: 2456-3358
Volume 08 Issue 12 December-2023, Page No.-3195-3202
DOI: 10.47191/etj/v8i12.10, I.F. – 7.136

Kombucha Cellulose Growth Comparison: Utilizing Branded Tea for Accelerating Architectural Biomaterial Production in Indonesia

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ABSTRACT: One of the most recent phenomenal biomaterial trends is produced by kombucha. Its cellulose becomes viral once it is experimented on as a synthetic fabric in architectural and fashion products. The uttermost issues still lie on the unstable layer and larger plane production, while most experimentation goes slow on organic processes. Kombucha cellulose production depends on the quality of 3 fundamental materials such as tea, sugar, and water. Growing on the surface of a liquid, the most challenging problem is media sensitivity towards the surrounding environment, as it reflects cellulose productivity. The debates involve a critique of the utilization of high-quality material that generally does not impact the cellulose building, even if producing a more delicious tea. However, the traditional home-brewed technique is still dominant in most places, especially in developing countries like Indonesia. This paper aims to suggest a reasonable material shift in traditional fermentation, especially for improving kombucha cellulose thickness, which is core in biomaterial production. A comparison is presented to compare kombucha cellulose productions using better quality ingredients. The kombucha is fermented under a natural tropic storing environment: a temperature between 26°C-30°C in a dark room and a humidity of 60%. An initiated sugar composition of 10%, a pH between 3-5.5, with final alcohol less than 5%. A variation of mixtures is introduced to verify stable cellulose productivity. A compilation of measurements is taken in 3 consecutive weeks to reveal the growth pattern. The result is a maximal range of thickness growth and a stable and productive layer of kombucha cellulose.

KEYWORDS: Architecture; Biomaterial; Cellulose, Kombucha; Production

INTRODUCTION

The recent biomaterial trends have impacted design production and sustainable construction (Sigiro, Maksum, & Dhaneswara, 2023). More brands show environmental concerns, greener approaches, and natural processes to meet new demands (Wacikowski & Michałowski, 2020). One of the most popular topics in biomaterial development is kombucha cellulose. Well-known for synthetic leather (Nguyen, et al., 2021), kombucha cellulose has now been experimenting with wider utilization such as product design, interior, and the latest development in architectural material (Laavanya, Shirkole, & Balasubramanian, 2021). Although the research is still limited, the interest is growing, showing various possibilities for creating architectural creative fabric from its cellulose (Wood, Verran, & Redfern, 2023). Specific research is required to balance out the cellulose production challenges and to improve material quality finishes while accelerating the traditional fermentation process as the centre of kombucha production (Amarasekara, Wang, & Grady, 2020). Hence, a comparison aims to fill the gap between two contrasts: the rise of the biomaterial industry and the preservation of traditional tea fermentation production with kombucha cellulose productivity.

Kombucha is a fermented drink that is commonly made from sweetened black tea (Amarasekara, Wang, & Grady, 2020). Traditionally home-brewed using a symbiotic culture of bacteria and yeast (SCOBY), the liquid has been the main target until the early 21st century. Just recently, more industries have been interested in shifting the primary outcome of kombucha fermentation from tea to cellulose production, starting from fashion textiles (Domskiene, Sederaviciute, & Simonaityte, 2019) to the latest building materials (Wacikowski & Michałowski, 2020). The kombucha fermentation has opened up the possibility for design perspectives to prioritize vegan, biotic, cruelty-free biomaterial creation using dried, dodgy-looking living organisms that formerly only being used as a starter to become the centrepiece in the design world (Laavanya, Shirkole, & Balasubramanian, 2021). The idea of using kombucha cellulose is inspired by the green philosophy from the ability of organic material to decompose back into the earth at the end of its life (Lianto, Husin, Thedyardi, Choandi, & Trisno, 2021). Its organicity contributes to developing less-allergy, breathable, and ethical products towards a zero-waste lifestyle yet up-cycle eco-living (Lianto, Trisno, Husin, & Choandi, 2020). With its alien, flexible, elastic, and fluid-looking texture, kombucha cellulose has easily become a point of interest (Angela & Devanthi, 2021), offering an iconic natural biodegradable material made from converting traditional fermentation to avant-garde experimentation

(Cavicchia & de Almeida, 2022). Kombucha cellulose can scale from faux to haute couture, from home to lab, and even from microbes to macro design (Laavanya, Shirkole, & Balasubramanian, 2021). This paradigm has been generating the idea of smallness becoming bigness in recent years (Nguyen, et al., 2021). Some believe kombucha production may offer an antidote for fast fashion (Wood, Verran, & Redfern, 2023), while others have confidence that this cellulose would be built as a future membrane for developing parametric yet naturalistic architecture (Laavanya, Shirkole, & Balasubramanian, 2021).

LITERATURE REVIEW

Growing rapidly, the majority of kombucha cellulose production preserves the goodness of traditional, natural, and organic processes as the fundamental procedures (Wood, Verran, & Redfern, 2023); asymmetrical, less productive, unpredictable results are commonly found despite successfully blurring the boundaries between biology, technology, and design. This means the general method of cellulose production believes that the challenge of making cellulose lies in the creative application rather than enhancing the productivity of the primary layer, generally using a standard yet avoiding variation to achieve steadiness (Laavanya, Shirkole, & Balasubramanian, 2021). The technique may be stable in a more controlled environment like the lab but may not be most effective if developed traditionally. The most common material production worldwide is produced at home or in small industries, especially in developing countries like Indonesia. The centre of production for Indonesians is also home-brewed, using local tea, guestimate measurement sugar, and utilizing groundwater while stored in a kitchen or a service area. As the production mainly focuses on producing fermented drinks, this may not present a significant problem in most Indonesian cases. The awareness of cellulose benefits is also seldom talked about in Indonesia, while the sustainability concepts have just begun in recent years, opening up the possibility for kombucha cellulose as one of the potential materials to be explored (Lianto, Husin, Thedyardi, Choandi, & Trisno, 2021).

To understand the general situation in Indonesia, most labourers and producers are traditional. It is not easy to shift perspective dramatically, although the kombucha drink is now being reborn and accepted widely as a new product. In Indonesia, kombucha cellulose is still a mere starter, with only a few uses as fertilizer or fodder. Although it has less function, the cellulose thickness is one of the most trustable indicators for high-quality fermentation in tropical countries like Indonesia. It is frequently taken as the indicator in the production process, yet trusting the appearance of kombucha cellulose as a higher-priced starter or an excellent accelerator for fermentation. This premise positioned cellulose with a perfectly rounded shape, bright colour, and texture to be valued as a high-quality starter and demanded highly in a wider market. The price is doubled or tripled when the size is bigger and wider. Various producers offer a range of colours, types, and sizes to create a more competitive market range. Most sellers believe in growing kombucha in aqueous media, less-intensity color tea, and highly sugary refined water to produce the ideal type for the Indonesian market. The issue with this method is that a longer duration is needed for thickening the cellulose; some require more than a month fermentation period, and few encourage a doubled brew. Replacing lower-quality tea with fine ones is not common, as the production price is higher, and the consumption of imported tea is still considered a luxury in Indonesia, though there is potential for accelerating pellicle growth (Azizah, Darma, & Darusman). Thus, this research aims to fill the gap of conserving the traditional method commonly practised in Indonesia while using branded tea to test the acceleration of cellulose production.

RESEARCH METHODS

The traditional kombucha fermentation method is refined by using various Twinings teas (Figure 1). Tea is brewed by using pristine pH 8+ with refined Gulaku sugar. A stable Natsilver starter is utilized: an organic starter producer in Tangerang. The fermentation is conducted in a dark place using the same equipment, utensils, and location with room temperature around 18°C-26°C, 60% humidity, 10% sugar, pH final 3-5.5, and final alcohol contains less than 5% to follow the general standard. The method neglects the practice of 25% sugared tea, which usually results in pellicle growth of around 0.3 to 1.2 cm as a comparison (Azizah, Darma, & Darusman) while questioning a generic 0.2 to 0.5 cm thickness (Shade, 2011). The main focus for the comparison is the pellicle growth; only its thickness is measured in 3 consecutive weeks, 7 days, 14 days, and 21 days until it is appropriately pro-biotically active (Greenwalt, Ledford, & Steinkraus, 1998). In addition, to test the fermentation stability, 1) a derivative variation is used to make a Jun (Alshifa/Airborne/Pure Native honey 5% + *gulaku* 5%), and 2) other tea brands combination to stimulate different interventions. This is taken as a conventional verification in traditional kombucha brewing.

Figure 1. Left:Traditional Kombucha Home-Brewing Fermentation using Jar, Tea and Sugar, Right: Pelicle Production

RESULTS AND DISCUSSION

The fermentation process is a natural, traditional, yet conventional home-brewed kombucha. An entire cycle is conducted consecutively with a few suspended yet overlapping processes. The first cycle shows an average of initiation 0.2-0.3 cm thickness and growth around 0.1-0.2 cm later while showing various ends. Less growth is shown by experiment number 6, a jun kombucha with the most negligible pellicle thickness at 0.01 cm, showing only transparent film at the surface of the kombucha. While the thickest is presented by experiment number 11, it is also a jun kombucha with a maximum growth of 1.3 cm. Experiment numbers exhibit steady pellicle growth: 1, 2, 3, 4, 7, 10, 13, and 15, while unpredictable growth is demonstrated by experiment numbers: 5, 6, 8, 9, and 12, displaying irregular measurement patterns. Only experiment number 6 shows no thickening after the first week, and number 11 shows uncommon yet surprising growth. Most growth in the first cycle is 0.2 cm, average growth is 0.175 cm, most minor growth is 0 mm, and thickest growth is 0.4 mm. Hence, the overall fermentation is dominated by steady pellicle growth.

Table 1. **Cycle 1 Kombucha Growth in the Premium Tea Media**

No	Brand	Type	Composition	Notes	Initiation	Pellicle thickness			Average growth
						7 Days (cm)	14 days (cm)	21 days (cm)	(cm)
1.	Twining	Darjeeling tea	Black tea	light	26/07/22	0.4	0.7	0.9	0.25
2.	Twining	Lady earl grey	Black tea Orange, lemon, bergamot	light Bergamot flavouring	26/07/22	0.2	0.3	0.5	0.15
3.	Twining	Pure green tea	Green tea	-	26/07/22	0.3	0.5	0.7	0.2
4.	Twining	Earl Grey	Black tea bergamot	Light a citrus bergamot flavour	17/08/22	0.25	0.35	0.45	0.1
5.	Twining	English Breakfast	Black tea	Medium rich	17/08/22	0.3	0.4	0.7	0.2
6.	Twining	Green tea	Pure green tea Pure honey native	Jun	17/08/22	0.01	0.01	0.01	0
7.	Twining	Chamomile	Poland camomile	delicate	17/08/22	0.2	0.3	0.4	0.1
8.	Twining	Ginger & Lemon	Natural Lemon & Ginger	Lemon peel, blackberry leaves, lemon grass natural flavourings	17/08/22	0.3	0.45	0.5	0.1

No	Brand	Type	Composition	Notes	Initiation	Pellicle thickness			Average growth (cm)
						7 Days (cm)	14 days (cm)	21 days (cm)	
9.	Twining	peppermint	Pure peppermint infusion	peppermint	10/09/22	0.3	0.4	0.7	0.2
10.	Twining	Green tea Earl grey	Green tea, bergamot flavouring	Green tea, bergamot flavouring	10/09/22	0.2	0.3	0.4	0.1
11.	Twining	Pure green tea	Alshifa natural	Jun	22/10/22	0.5	1.3	1.3	0.4
12.	Twining	Jasmine green tea	Airborne clover	Jun	22/10/22	0.5	0.8	1	0.25
13.	Twg lady grey + the au jasmine	mix	mix	mix	13/11/22	0.5	0.7	0.9	0.2
15.	Twg Darjeeling + the au jasmine	mix	mix	mix	13/11/22	0.7	0.9	1.1	0.2

Generally, slower growth and thinner ends initiate the second cycle. The second cycle shows an average of initiation 0.2-0.3 cm thickness, a few contrasts around 0.5-0.7 cm, and mainly growing around 0.1-0.2 cm later while showing contrast ends. The least growth is shown by experiment number 6, a jun kombucha with a thickness of 0.02 cm showing only translucent film at the surface of the kombucha. While the thickest one is presented by experiment number 11, it is also a jun kombucha with a maximum growth of 1.3 cm. Experiment numbers exhibit steady pellicle growth: 1, 2, and 10, while unpredictable growth is demonstrated by experiment numbers: 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, and 14, displaying irregular measurement patterns. The general experiment in cycle 2 shows thickening, while most experiments exhibit uncommon yet surprising growth. Most growth in the second cycle is 0.1 cm, average growth is 0.1825 cm, least growth is 0.005 cm, and thickest growth is 0.425 cm. Although the fermentation is dominated by unsteady pellicle growth and shows an irregular pattern in terms of measurements, the general tendency for the second cycle shows slightly more growth from the former, meaning the fermentation media has become more robust.

Table 2. Cycle 2 Kombucha Growth in the Premium Tea Media

No	Brand	Type	Composition	Notes	Initiation	Pellicle thickness			Average growth (cm)
						7 Days (cm)	14 days (cm)	21 days (cm)	
1.	Twining	Darjeeling tea	Black tea	light	20/12/22	0.3	0.6	0.8	0.2
2.	Twining	Lady earl grey	Black tea Orange, lemon, bergamot	light Bergamot flavouring	20/12/22	0.3	0.4	0.5	0.1
3.	Twining	Pure green tea	Green tea	-	20/12/22	0.2	0.45	0.6	0.15
4.	Twining	Earl Grey	Black tea bergamot	Light a citrus bergamot flavour	10/01/23	0.2	0.4	0.5	0.15
5.	Twining	English Breakfast	Black tea	Medium rich	10/01/23	0.3	0.4	0.65	0.175
6.	Twining	Green tea	Pure green tea Pure honey native	Jun	10/01/23	0.01	0.02	0.02	0.005
7.	Twining	Chamomile	Poland camomile	delicate	10/01/23	0.2	0.3	0.35	0.075

No	Brand	Type	Composition	Notes	Initiation	Pellicle thickness			Average growth (cm)
						7 Days (cm)	14 days (cm)	21 days (cm)	
8.	Twining	Ginger & Lemon	Natural Lemon & Ginger	Lemon peel, blackberry leaves, lemon grass natural flavourings	10/01/23	0.25	0.5	0.5	0.125
9.	Twining	peppermint	Pure peppermint infusion	peppermint	11/02/23	0.25	0.4	0.75	0.25
10.	Twining	Green tea Earl grey	Green tea, bergamot flavouring	Green tea, bergamot flavouring	11/02/23	0.1	0.3	0.5	0.2
11.	Twining	Pure green tea	Alshifa natural	Jun	20/03/23	0.45	1.2	1.3	0.425
12.	Twining	Jasmine green tea	Airborne clover	Jun	20/03/23	0.4	0.8	1.0	0.3
13.	Twg lady grey + the au jasmine	mix	mix	mix	10/04/23	0.6	0.8	0.9	0.15
14.	Twg Darjeeling + the au jasmine	mix	mix	mix	10/04/23	0.6	0.8	1.1	0.25

Generally, faster growth and thicker ends initiate the third cycle. The third cycle shows an average of initiation 0.3-0.5 cm thickness with few contrasts and mainly growing around 0.1-0.2 cm later while showing mostly more than 0.5 cm ends. The least growth is shown by experiment number 6, a jun kombucha with pellicle thickness at 0.02 cm showing a translucent film at the surface of the kombucha. While the thickest one is presented by experiment number 11, it is also a jun kombucha with a maximum growth of 1.4 cm. The steady pellicle growth is exhibited by experiment numbers 2 and 10, while unpredictable growth is demonstrated by experiment numbers 1, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, and 14, displaying irregular measurement patterns. All the experiments show thickening, while most show uncommon yet surprising growth. Most growth in the third cycle is 0.1 and 0.2 cm, the average growth is 0.1910 cm, the least growth is 0.05 cm, and the thickest growth is 0.45 cm. Thus, although the fermentation is dominated by unsteady pellicle growth, the third confirmed steady improvement.

Table 3. Cycle 3 Kombucha Growth in the Premium Tea Media

No	Brand	Type	Composition	Notes	Initiation	Pellicle thickness			Average growth (cm)
						7 Days (cm)	14 days (cm)	21 days (cm)	
1.	Twining	Darjeeling tea	Black tea	light	21/05/23	0.5	0.75	0.95	0.225
2.	Twining	Lady earl grey	Black tea Orange, lemon, bergamot	light Bergamot flavouring	21/06/23	0.3	0.5	0.7	0.2
3.	Twining	Pure green tea	Green tea	-	21/06/23	0.35	0.5	0.7	0.175
4.	Twining	Earl Grey	Black tea bergamot	Light a citrus bergamot flavour	12/07/23	0.3	0.4	0.6	0.15
5.	Twining	English Breakfast	Black tea	Medium rich	12/07/23	0.35	0.45	0.75	0.15
6.	Twining	Green tea	Pure green tea Pure honey native	Jun	12/07/23	0.1	0.1	0.2	0.05

No	Brand	Type	Composition	Notes	Initiation	Pellicle thickness			Average growth (cm)
						7 Days (cm)	14 days (cm)	21 days (cm)	
7.	Twining	Chamomile	Poland camomile	delicate	12/07/23	0.25	0.35	0.55	0.15
8.	Twining	Ginger & Lemon	Natural Lemon & Ginger	Lemon peel, blackberry leaves, lemon grass natural flavourings	12/07/23	0.35	0.45	0.6	0.15
9.	Twining	peppermint	Pure peppermint infusion	peppermint	3/08/23	0,35	0,45	0,8	0,225
10.	Twining	Green tea Earl grey	Green tea, bergamot flavouring	Green tea, bergamot flavouring	3/08/23	0,3	0,4	0,5	0,1
11.	Twining	Pure green tea	Alshifa natural	Jun	4/08/23	0,5	1,3	1,4	0,45
12.	Twining	Jasmine green tea	Airborne clover	Jun	4/08/23	0,55	0,8	1	0,225
13.	Twg lady grey + the au jasmine	mix	mix	mix	8/08/23	0,45	0,75	0,95	0,25
14.	Twg Darjeeling + the au jasmine	mix	mix	mix	08/08/23	0,75	1	1,1	0,175

Following the 3 cycles, although there is a slightly uneven initiation process, the overall comparison shows a tendency for more productive pellicle growth. The first is the most consistent growth pattern, while the last shows the most irregular growth pattern, though more cycles mean steadier growth with unbalanced variations in this experiment. Even if there is a tendency for slight changes from cycle to cycle, the general pattern of the pellicle growth displays a better end in the last experiment. A similar pattern of measurements is generally founded on the same experiment number; this means the tea types show a stable and firm characteristic in the fermentation, even when combined or mixed with different ingredients. Surprising results are shown by jun kombucha; At the same time, typical fermentation suggests a combination of sugar and black tea as the strongest kombucha type.The result of this experiment exhibits jun as the best cellulose producer, resulting in the thickest pellicle with the most consistent growth pattern. With an expended time, a notable finding shows an isolated Jun pellicle once resulted in a 1.8 mm after 3 cycles (Figure 2). There is no notable productivity of black tea found from the experiment in terms of pellicle growth when compared with milder ingredients such as chamomile, peppermints, etc. This means the other types of tea from this particular brand show a relatively typical tendency of pellicle productivity in this experiment. The anomaly was only found in experiment number 6, the only jun made of Native Pure Honey because it produces the thinnest pellicle layer. Compared with kombucha standard growth and Indonesian common cases, this experiment result shows a steady yet higher range of pellicle productivity.

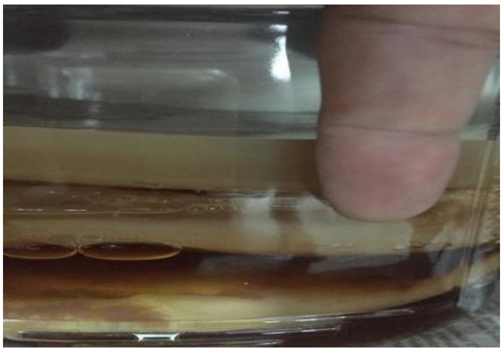

Figure 2. The Thickest Jun Pelicle ever Produced after 3 Cycles

CONCLUSION

Natural kombucha fermentation is a long, organic process. The organicity of the material affects the delivery system, including the productivity and the final of kombucha pellicles. Although the procedure and technique have been standardized, the outcome is often unpredictable when tested in home brewing. In this research, home brewing is prioritized and perfected to cover the most significant audience yet stimulating architecture biomaterial production at home as a bottom-up strategy for Indonesia. The comparison provides a general understanding that refined quality ingredients generate a higher productivity of kombucha cellulose. It rejects the common perception that kombucha can strive with generic ingredients by positioning the final pellicle thickness at the highest range of possible sizes. However, these experiments focus only on the productivity of layers rather than covering wider surfaces as the research gap for producing larger planes in architecture. The thickness of the pellicle is beneficial to provide the possibility of strength, elasticity, and insulation of the planned biomaterial. In the end, premium, branded, or fine tea has demonstrated an excellent accelerator if intended to achieve thicker results. This may deliver a greater layer for building cellulose, covering one of the most difficult tasks of raising the kombucha pellicle, especially for developing architectural biomaterial in Indonesia.

ACKNOWLEDGEMENT

Thanks to LPPM-UNTAR (Institute for Research and Community Service – Universitas Tarumanagara) for funding this research, Deni Soenarto, and Steven Chen, who helped collect the data.

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